ANALISI DI SOSTENIBILITÀ DEL MERCATO FERROVIARIO FINALIZZATA ALLA DEFINIZIONE DELLA COMPONENTE B DEL PEDAGGIO DEI SEGMENTI DI MERCATO

EVALUATION OF THE *ABILITY TO PAY* OF PASSENGERS' SEGMENT AND SIMULATION OF PRICING SCENARIOS.
(PUBLIC CONSULTATION FINAL VERSION) 28/09/2023

ANALISI DI SOSTENIBILITÀ DEL MERCATO FERROVIARIO FINALIZZATA ALLA DEFINIZIONE DELLA COMPONENTE B DEL PEDAGGIO DEI SEGMENTI DI MERCATO
EVALUATION OF THE ABILITY TO PAY OF PASSENGERS' SEGMENT AND SIMULATION OF PRICING SCENARIOS.
Public Consultation final version, 28/9/2023

Authors: **Paolo Beria**

Photo by:

TRASPOL – Laboratorio di Politica dei Trasporti

Dipartimento di Architettura e Studi Urbani, Politecnico di Milano
Via Bonardi 3, 20133, Milano, Italy. http://www.traspol.polimi.it

LABORATORIO DI POLITICA DEI TRASPORTI
TRASPOL
RESEARCH CENTRE ON TRANSPORT POLICY

CONTENTS

1. INTRODUCTION

The present report describes the structure and the data used in the estimation of the impact of the new Train Access Charge system (hereinafter TAC) for Italian national rail network, as requested by the Italian Transport Regulation Authority (hereinafter "ART", Autorità di Regolazione dei Trasporti).

The study has been commissioned by RFI SpA, the Italian Infrastructure Manager (hereinafter "IM") and is aimed to ground the ART Resolution 95/2023 entitled "*Revisione dei criteri per la determinazione dei canoni di accesso e utilizzo dell'infrastruttura ferroviaria approvati con la delibera n. 96/2015 ed estensione e specificazione degli stessi per le reti regionali interconnesse*" in the part related to the part B of the pricing.

Differently from previous applications, the Ability to Pay (hereinafter "AtP") of a train service is managed here through a complex approach that is not entirely deterministic, capable of taking into account different strategic behaviours of the industry. The characteristics of the current exercise can be summarised as follows:

1) The effect of the pricing is simulated through an iterative approach, not linear and including feedbacks that aim at reproducing the search of an equilibrium between differential costs and revenues operated by the railway undertakings (hereinafter "RU") under changing pricing conditions;

2) The AtP is proxied[1] by composite elasticities derived from the previously described feedback, providing the change in IM's revenues in function of unitary charge; similar elasticities of unitary charge are produced also for passengers·km and trains·km.

3) The elasticities are estimated at a very detailed scale, describing the entire Italian rail supply through approx. 500 "lines", or more precisely "groups of similar train missions". This level of detail allows the IM not only to estimate the response of the revenues to the prices, but also to define from scratch the pricing groups ("*binomi*").

4) The overall composite elasticity of a line depends on the following main ingredients: the share of toll on operating costs, the elasticity of rail demand to prices, the behaviour of the RU in adapting to changing prices. In principle, the approach allows also to consider varying cost functions of RUs, but this part has been treated in a very limited way due to lack of sufficiently detailed and reliable cost functions.

The estimation described in the following adopts two different approaches for freight and passenger demand, as outlined in Figure 1.

---

[1] For a more extensive discussion on the relationship between AtP and elasticity, see Section 4.2.
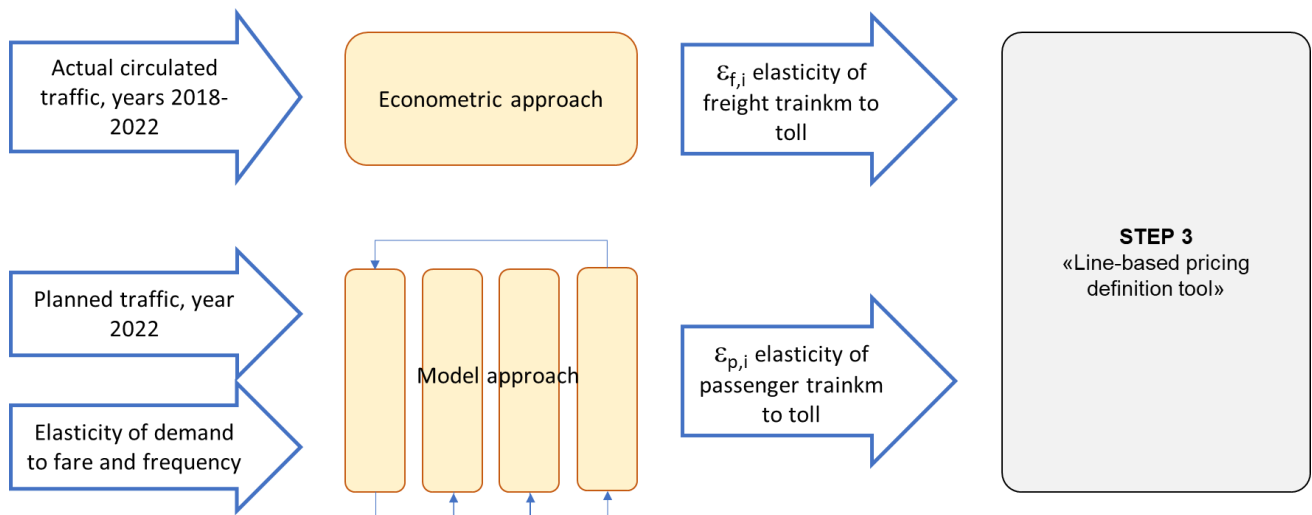
Figure 1. Schematisation of the approach used for freight and passenger traffic tolls definition.

The two approaches will be described extensively in the following sections (passengers segment) and in annex (freight segment). In short, the availability of a cross-sectional dataset including quantities of tonkm and trainkm under varying tolls has let us to adopt an econometric approach estimating directly the searched elasticities for freight traffic. To the contrary, passenger traffic had much more stable prices in the previous regulatory period and moreover the demand data is not available (passenger·km), making impossible to derive statistically a sound elasticity estimation. The only variations of TAC during the current regulatory period are those related to the discount of Part B for *Premium* and *Basic* segments during COVID-19 crisis. However, this discount is not only partial (*Regional* segment did not have it), but it was applied in a period of lack of demand when we cannot absolutely consider the behaviour of RUs as an ordinary response to a price variation. For these reasons, **we followed a modelling approach** in which all steps of decision from the variation of toll to the variation of traffic are modelled.

Note: when in the title of section or paragraph appears "[CONFIDENTIAL]" it means that the data described and used in the section has been communicated to the authors of this report as confidential, either from RFI/FSI or from own sources that, to date, are not published.

This draft report is structured as follows. The following Section 2 is dedicated to the description of the architecture created to estimate the elasticities of the passengers' segment. The architecture is made of three modules named "steps". Step 1 transforms the original dataset of single trains into a smaller dataset organised in lines according to the structure of the demand model i-TraM. Step 2, working at the line level, estimates the production costs, the elasticity of demand to price and frequency and simulates the behaviour of firms. Step 3, using Step 2's results estimates revenues, tkm and passenger variation due to different TAC sets. Section 3 presents the results of Step 2, focusing in particular on RU behavioural model results and commenting derived elasticity estimates. Section 4 is dedicated to the presentation of the results of the application of different pricing schemes. It includes also some important considerations on the criteria behind the definition of pricing schemes. Section 5 is an annex presenting more in detail the transport model used to estimate demand elasticities used in Step 2.

2.1 GENERAL STRUCTURE OF PASSENGERS' SEGMENT

As described above, **the estimation of elasticities for the passengers' segment follows a modelling approach, since the available data has no sufficiently variability for a statistical treatment**.
The general idea follows the one used by DB Netz and depicted in Figure 2. There, it is assumed that there is a direct cause-effect chain from the change of path pricing by DB Netz to the change of train·km produced by RUs, passing through a change of total RU costs, RU prices and demand. All these consequent steps are modelled through one single elasticity parameter per step[2], assuming that a certain change in one variable determines a rigid change in the dependent one.
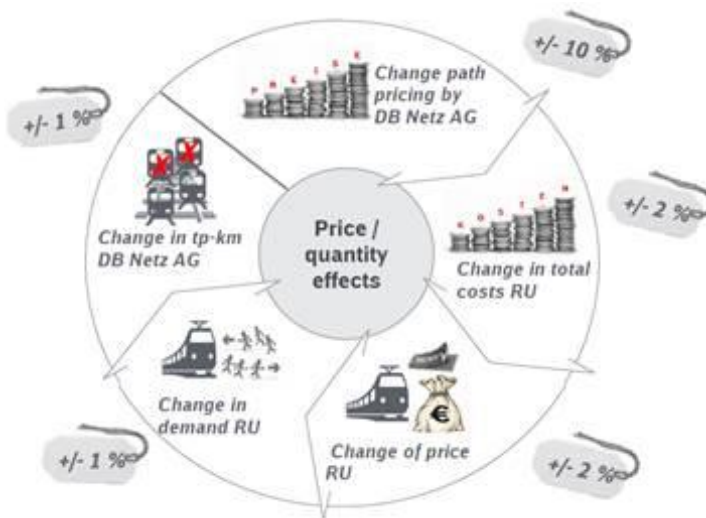
Figure 2. The approach to elasticity estimation followed by DB Netz. Source: Network Statement Annex 6.1.

This approach and its assumptions present some limitations, that must be verified in terms of realism or challenged.
Firstly, the independent variable is always assumed to be one for every step. This is reasonable for some of them (e.g. the effect of change in RU total costs depending from the change of DB Netz path prices) but might be too simplified for others. For example, the RU could respond to a change in its total costs by tuning other variables than the sole users' price.
Secondly, the concept of elasticity (moreover if *one* elasticity) assumes a rigid response on the step: a rise of tolls rigidly determines a certain reduction of production and vice versa. Actually, we can rather assume that decisions, especially, those related to companies' strategies, might not follow such a deterministic development.
Thirdly, the feedbacks seem more articulated than the circular one assumed by the source. In particular, the behaviour of the IM interacts with the one of each RU.
To overcome these limits and produce a more realistic, but also more flexible tool, to estimate the effect on IM revenues of path prices, we adopted the following scheme, which is derived from the one initially foreseen by the IM in the previous exchanges with ART.

---

[2] This hypothesis is particularly restrictive in describing the "change in demand RU" and in "change in tkm".

Figure 3. General approach to composite elasticity estimation.

At t=1, the IM varies the toll of a train path (increasing or decreasing). This determines a change in RUs' costs according to the share of the toll in RU's costs. From this passage on, each RU may react varying (or not) any of the supply parameters: the final customers' **price**, the **frequency** and the **capacity** of trainsets that together increase or reduce the production in trainkm, the quality of the service, etc. In principle, 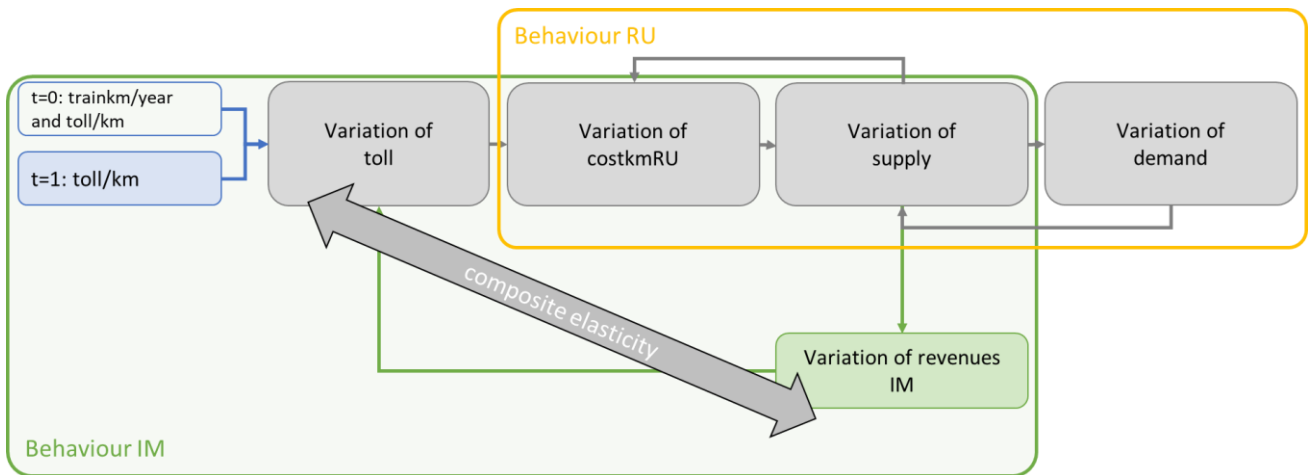any change in the supply may determine a change in the unit costs of the train, but we would need very detailed and realistic cost functions which are not available. Similarly, any variation of supply may induce a variation in demand. For example, a reduction of frequencies will reduce the number of passengers in favour of other modes or routes. Again, the variation of demand is not taken passively by the RU, that can evaluate whether it is better for itself to – say – raise prices or reduce frequency. All of this belongs to the domain of the RU, but clearly has a consequence on IM. While a variation of train fares may not change the RU production, a strategy working on frequency has instead an impact on IM revenues. For this reason, the output of the entire RU model is **the variation of supply consequent to the variation of tolls**.

Once we obtain the variation of supply, we have also the variation of IM revenues due to the variation of toll. This can be represented in a concise way through an **average elasticity**, which is the main goal of this modelling exercise:

$$\varepsilon R(ut) = ((R_1 - R_0) / R_0) / ((tac_1 - tac_0)/tac_0)$$

being:
R: Total Revenues of the IM (€/year)
tac: unitary train access charge (€/trainkm)
0 and 1: initial and current year.

It is worth recalling that elasticity is not a constant of a market, but a function of the level of ut. Since for the current application we need a continuous value, we create numerically a continuous function of average elasticities. Moreover, in principle, elasticity is not symmetrical: a reduction of toll may have a totally different elasticity coefficient than the one of an increase, because demand respond asymmetrically to the price signal.

The general procedure described above is practically implemented in a 3-steps procedure, each consisting of submodules aimed at solving specific problems. The flow is depicted in Figure 4.
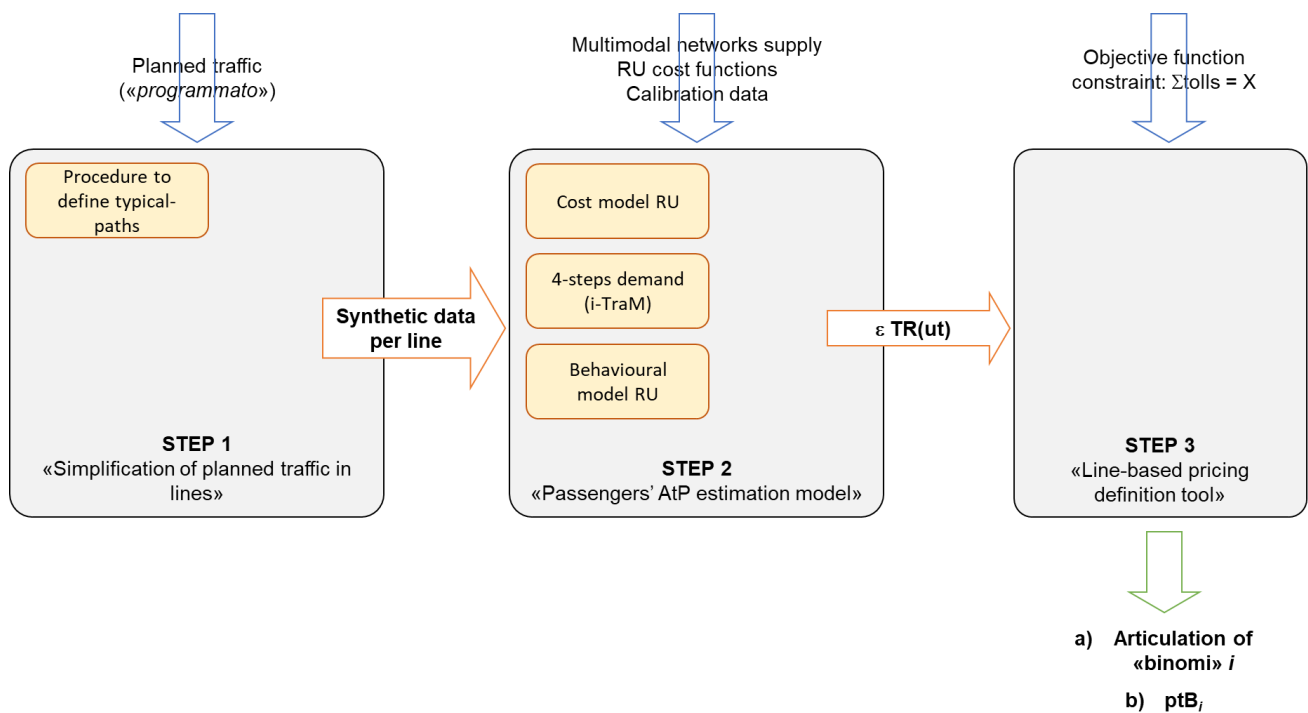
Figure 4. Schematisation of the 3-stepf of Passenger traffic AtP estimation.

Step 1 is aimed at passing from the list of **each planned train** of the base year (2022), provided by the IM, to a more compact description of planned traffic in a smaller number of "lines". With "line" we mean here a group of sufficiently homogeneous typical missions, as in Figure 5.

The reason of this simplification is twofold. On the one side this is needed to pass from 25042 single passengers trains of 2022 to a more manageable list of 523 lines. On the other side, an input in *lines* corresponds to the output of the 4-steps transport model used in Step 2 (see below) to estimate users' elasticities. Overall, the aim of Step 1 is to produce the main input of the model, and from Step 2 on the line will be the smallest unit of work. Working at "*binomio*" level, namely the aggregation of services with similar AtP according to regulation, is not sufficiently detailed and moreover the articulation of *binomia* is an output of the work and not the input.
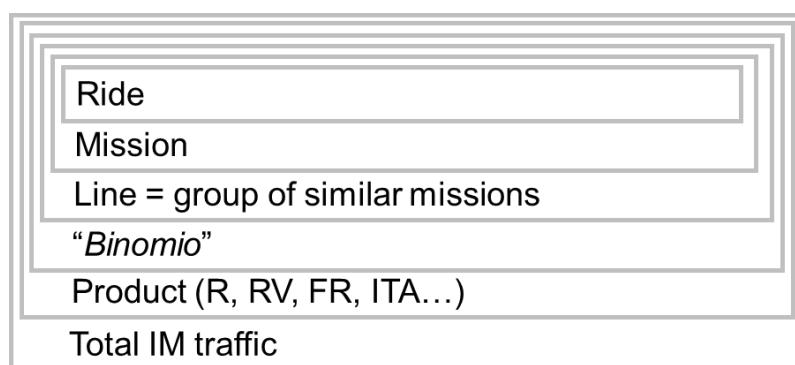
Figure 5. Exemplification of data structure, from single train ride to total traffic.

Step 2 is the main engine of the estimation and is **run independently for each of the 523 lines**. It receives the list of lines, together with their characteristics such as average toll, total trainkm, contract of service the trains belong to, etc. All fields will be described later in section 2.2. Step 2 is made of important sub-modules, that are:

  a. The 4-step transport model (*i-TraM*) that is used to estimate the elasticity of final demand (passengers) to the variation of fares and/or frequency.

b. The production costs functions.
c. The RU/Regions/Ministy's behavioural model.

Step 2 is based on normalised variations, since not all relevant variables are known, such as the real passenger number per train or line, and the real revenues. The output of Step 2 is a discontinuous average elasticity function linking the variation of IM revenues and trainskm, per line, to the variation of tolls, per line. **These elasticities $\varepsilon_{REVENUES}$(tac) *and* ε_{TKM}(tac) are a sort of shortcut, incorporating in themselves all the actions and reactions, some non-deterministic, described above in Figure 3**. In other words, we create a direct link between input and output, that is valid in the neighbourhood of starting conditions, that avoids running entire parts of the model at every iteration of the pricing definition.

Step 3 is a tool that helps the IM to set the tolls according to all intermediate "elasticities"[3] that Step 2 packed into the average elasticities $\varepsilon_{TKM}(tac)$ and group them into a limited number of *binomia*. Step 3 is the phase in which is implemented a chosen criterion of pricing, while the previous ones were totally neutral. So, for example, in Step 3 we can define a set of tolls that allows cost coverage, another that maximises the revenues and another one that maximises the passengers.

In the following sections we will describe in detail each of the three steps outlined here.

2.2 STEP 1 – SIMPLIFICATION OF TIMETABLE IN "TYPICAL MISSIONS"

Step 1 consists of two main modules that shrink the complete dataset of trains in a compact version based on lines. The outcome dataset includes also additional information such as the typical rolling stock and the contract of service the train belongs to.

2.2.1 Definition of typical missions

INPUT
i. *Programmato 2022* **(planned timetable 2022).** Source: RFI. **Use**: list of single trains, to be grouped in lines, including origin, destination, RU, yearly and unit toll paid, trainkm, mission length, market segment 2022, number of trains, speed, electric consumption, type of train.
ii. **Timetable. Use**: identification of paths of each train and grouping into lines and products with revised classification.

The module is fed with the list of planned trains and the timetable and produces the grouping of trains in lines. This grouping is used both in the i-TraM transport model to describe the services and produce the elasticities, and by the following steps to maintain a manageable input.

This activity is carried out through a semi-automatic procedure, that identifies the mission (=list of stops) of each train, groups the identical ones and evidences the non-identical ones letting an operator defining the rules for assimilating or not non-identical missions.

The example below in Figure 6 clarifies the concept. For example, trains 9678 to 9640 are not identical, but are grouped together because all going from Milan and Naples and calling at Rome and just another intermediate stop, typically Bologna. They are commercially identified as "fast".

...o||o||o|o.
...o||o||o|o.
...oo||||ooo.
...o||o||o|o.
...oo||||ooo.

---

[3] We use in an improper way the term elasticity, as, for example, the 4-steps transport model is based on behavioural models and not on the economic definition of demand elasticity. But an average elasticity is always computable as the ratio of the percentage variation of one variable and of another, whatever is the source of such figures.

In other cases, a train is attached to a line because "orphan", namely a train doing a singular mission and/or at the extremities of the period of service (e.g. the first and last train of the day that call at all stops instead of the main ones).
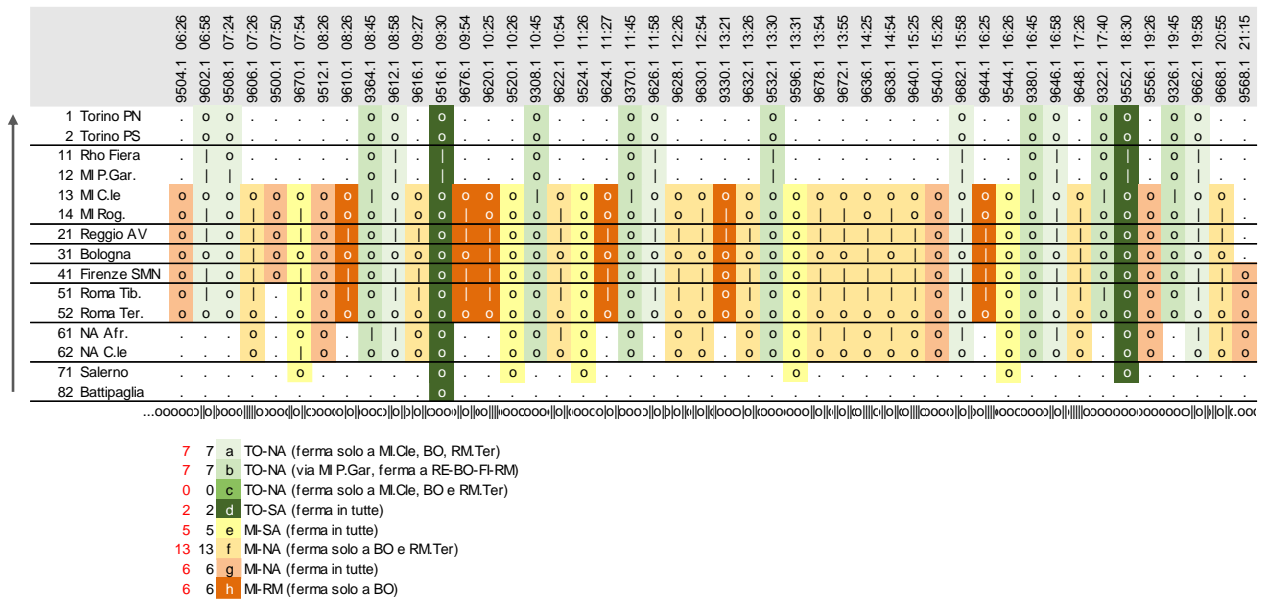
Figure 6. Example of semi-automatic identification of typical missions and lines.

Moreover, each line is associated with a **product class**, used as a reference in further modelling/analytical steps. The definition of product classes follows official classifications used by railway companies, with some adaptation aiming to guarantee homogeneity and comparability among different lines (Table 1). In particular, high-speed trains managed by TI (FR, FA) and NTV are gathered in a unique class. On the other hand, the "regional train" class, which includes most of the lines, is split into three sub-segments, namely: fast regional (Regionali Veloci/RegioExpress) services, suburban/metropolitan services, and "normal" regional services. Furthermore, airport services are grouped into a separate class.

Table 1. Classification of modes and sub-modes of i-TraM transport model.

Transport mode	i-TraM code	Description of sub-mode
RAIL	A	*High-speed train*
	C	*Conventional long-distance train / Intercity*
	D	*Direct train / RegioExpress / Interregio*
	R	*Regional train*
	S	*Suburban train / SBahn*
	L	*Night train*
OTHER MASS TRANSIT	M	*Metro*
	T	*Tram / Light rail*
	F	*Funicular, Cable car, Gondola*
BUSES AND COACHES	E	*Extraurban bus*
	U	*Urban bus*
	X	*Express coach – long-distance*
NAVIGATION	N	*Navigation (any)*
	O	*Ferries (Ro-Ro services)*
AVIATION	V	*Flights*

The outcome of the lines and product class grouping is reported in Table 2.

Table 2. Number of lines identified, per company and class of service.

RU	Classification	Lines	Trainkms
	Tecnici	3	7.058.313
BI	R	4	403.067
EAV	R	2	337.294
FEdGA	R	1	164.145
ITALO	italo	21	29.452.736
RCCIT	EC	2	350.478
	EN	1	177.877
SAD	R	2	1.371.453
SNCF	EC	1	545.113
ST	R	2	1.124.000
TI	aerop	1	1.444.362
	EC	7	1.964.086
	EN	2	991.813
	FA	13	10.453.431
	FB	5	4.452.072
	FR	39	50.232.328
	IC	25	16.640.135
	ICN	11	8.538.910
	R	249	100.291.483
	RV	34	35.650.452
	S	51	27.821.559
TRENORD	aerop	1	84.333
	EC	3	1.286.282
	R	27	11.858.388
	RV	8	8.722.575
	S	14	10.945.664
TUA	R	1	365.972
Total		**530**	**332.728.318**

2.2.2 Creation of the lines' dataset

INPUT
  i. *Programmato 2022* **(planned timetable 2022).** Source: RFI
  ii. **Passengers counts of regional trains 2022**. Source: Trenitalia. **Use**: recognition of the Contract of Service (region or Intercity) of each train.
  iii. **Capacity of train compositions**. Source: Trenitalia and our elaborations. **Use**: estimation of capacity of each train composition.

The module takes the original database of planned timetable and integrates it with additional information:
  ▪ The length and duration of the mission.
  ▪ The average toll paid.
  ▪ The total of trains·h, in addition to trains·km.
  ▪ The rolling stock: type, group, single/double composition.
  ▪ The capacity of seats.
  ▪ The i-TraM line it is associated, with its relevant information: company, type of service.

- The contract of service of the line[4], obtained according to the following scheme:
  - Criterion 1: Intercity and IntercityNotte trains are contracted with the Ministry of Transport.
  - Criterion 2: the train is listed in regional passengers count and the contract is know.
  - Criterion 3: some companies operate uniquely for one region (e.g. Trenord = Lombardia)
  - Criterion 4: origin and destination belong to the same region
  - Criterion 5: origin and destination of an unknown train are the same of a known train of the list of passengers' counts.
  - Criterion 6: remaining trains are manually evaluated and attributed to a contract.
- The prevalent service group of the previous regulatory period ("*binomio*")
- The cost coverage capability (100%: market service, not subsidised; <100%: revenues cost ratio)
- The cost of energy.

Then, all single trains grouped per line, obtaining a final dataset as exemplified in Table 3. This output is the input of STEP 2.

---

[4] Regional trains typically "belong" to a contract signed between the operator and the region. However, some interregional trains "belong" to two regions. For this reason, we have a second field to keep this additional information.

Table 3. Example of STEP 1 output.

Field	Example 1	Example 2
id_iTraM_line	**R.02203.XXX**	**A.01277.NTV**
Line description	Foggia – Sannicandro Garganico	italo RM Termini – Venezia Santa Lucia
RU (RFI client)	FEdGA	ITALO
Classification	R	italo
Trains/year	5770	1835
Average trip duration (h)	0,75	4,00
Average seats/train	120	472
Average lenght on RFI network	28,4	514,2
Trainkms/year	164.145	943.537
Average toll	1,97	4,55
Average toll - pt A	0,30	0,35
Average toll - pt B	1,67	4,20
Toll €/year	323.707	4.294.027
Rolling stock group 1	EMU reg piccola--1	AV--1
share of group 1	67%	100%
Rolling stock group 2	ALe--1	
share of group 2	33%	0%
Service group 2022 lev 1	5 OSP - REG	1 Open Access - Nazionali - Premium
Service group 2022 lev 2	5.6 OSP - REG - No Nodo	1.6 Open Access - Nazionali - Premium - P-base
Rides/day	15,8	5,0
Contract of Service 1	Puglia	mercato
Contract of Service 2		
Ferry leg	ita	ita
Cost coverage capability	29%	100%
Unit average cost of energy	0,15	1,04

Representing the lines is particularly challenging because of substantial overlaps. Figure 7 shows some of the most relevant dimensions: the average length of the missions included in the line, the total trains/year grouped in a line, the commercial classification of the trains and their average access charge.
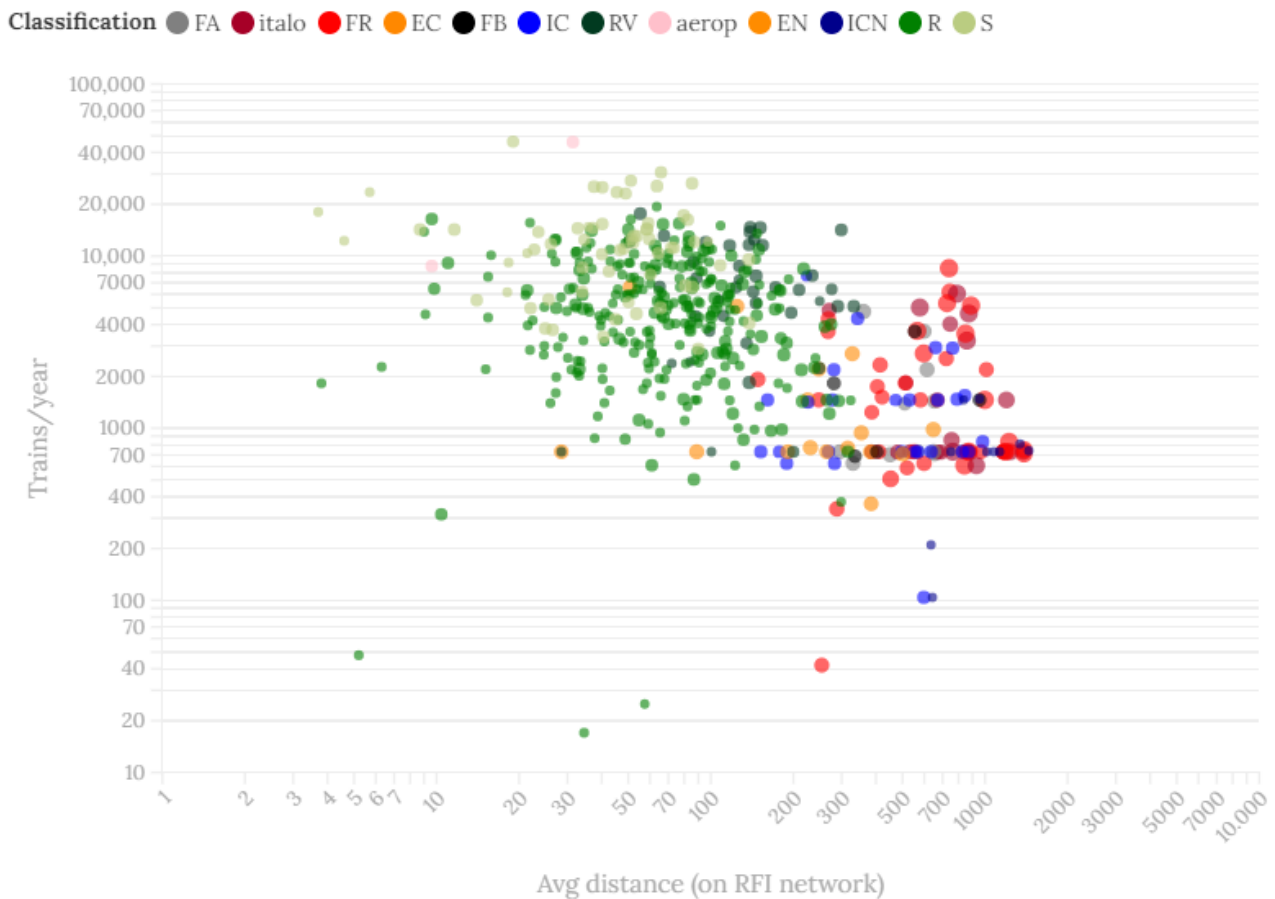
Figure 7. Representation of RFI total traffic. Each dot represents one line as classified in STEP 1. Size of dot represents the average toll of 2022.

2.3 STEP 2 – MODELLING THE ABILITY TO PAY OF PASSENGERS

The bulk of calculations is included in Step 2, which works at the very detailed level of "lines" created by Step 1. The outcomes of Step 2 are **vectors of average derived elasticities** of trainskm, paxkm and IM revenues to TAC variations: $\varepsilon_{TKM}(tac)$, $\varepsilon_{PKM}(tac)$, and $\varepsilon_{REVENUES}(tac)$, as described later in section 2.3.4. Actually, the model, described in the following, is applied repeatedly obtaining **functions of elasticity to TAC variation**s. These functions will be the input of the following Step 3, that will calculate the effect in terms of revenues, traffic and passengers of different pricing scenarios.

STEP 2 – Overall scheme (extraction of elasticities)
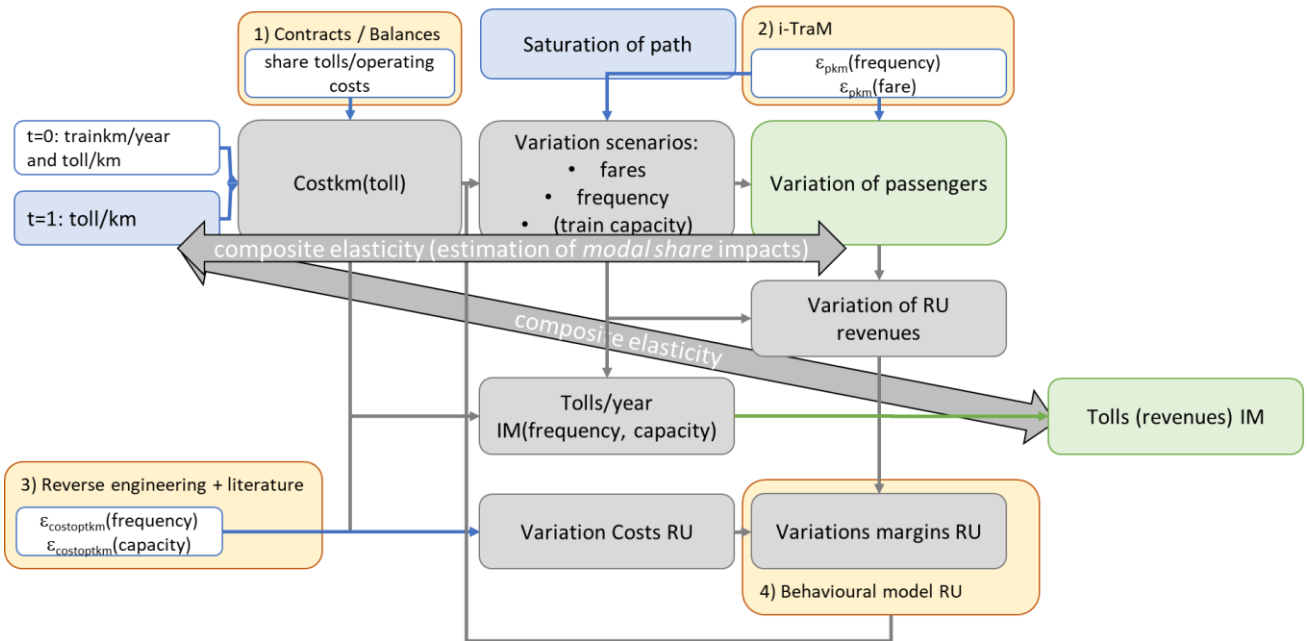
Figure 8. Schematisation of the overall STEP 2 structure. In yellow, the modelling steps.

Figure 8 details the operations of Step 2 and their feedbacks:

1. At t=1 **the IM modifies the TAC** (increase or decrease);
2. The change of the TAC **changes the running cost of the RUs** (sub-step 1), according to the share of TAC determined from various sources as documented in Paragraph 2.3.1;
3. In response to the new running costs, the **RUs modifies the supply parameters**: fares, frequency (trainskm) and/or capacity of trainsets (for example by switching to double compositions). The **new supply is associated to different production costs**, in addition to the new TAC, as performed by sub-step 3;
4. In parallel, in response to the new supply parameters (fares and frequency only), **passengers change their behaviour** switching among alternative modes or alternative paths. The response of passengers is performed by sub-step 2 and is based on i-TraM multimodal transport model, as documented in sections 2.3.2 and 5;
5. The shifts of demand (and new fares) modify the revenues of the RUs. **The equilibrium between supply parameters and demand behaviour** is modelled in sub-step 4 through a simplified enterprise behavioural model based on revenues and costs margin;
6. Once obtained the new equilibrium, all needed parameters are known (quantity of demand, paid fares, unit costs, unit access charges, trainskm), and the **calculation of derived elasticities** can be performed.

It is important to say that the average elasticities allow, in the neighbourhood of the imposed TAC change, to **shortcut the entire iterative modelling**. Since the target TACs are not known – they are the final result of the modelling – we need to calculate the elasticities for different levels of TAC, creating the already mentioned elasticity functions.

In the following paragraphs we will describe more in detail the construction of cost functions (sub-step)1 and 3), the demand model (sub-step 2) and the RU's behavioural model (sub-step 4).

2.3.1 Cost functions

Reliable and *rich* cost functions are needed to estimate:

a. The share of tolls on total operating costs (sub-step 1);
b. The effect on operating costs of frequency and capacity changes (sub-step 3).

In principle, needed functions must link operating costs with the relevant cost drivers, namely **distance**, **rolling stock**, **commercial speed** and **timetable structure**. Unfortunately, cost data obtained from RU consultations and from public sources is largely insufficient to perform such estimation, with the exclusion of some traffic segments.

For this reason, we abandon the hypothesis of having functions capable of reflecting the timetable structure[5], limiting to the other parameters.[6] We also hypothesise that the drivers are mainly additive because influencing different cost components (e.g. *commercial speed is a driver for the part of costs linked to travel time and not to trainskm*) and that we can use a linear combination:

$$C_i = k0_i + k1_i \cdot dist + k2_i \cdot seats \cdot dist + k3_i \cdot time + energy$$

With:

C_i: total operating cost of an homogeneous category of train services i

$k0$: fixed cost per single event [€/train]

$k1$: cost per km, fixed part [€/trainkm]

$k2$: cost per km, part depending from seats [€/seatkm]

$k3$: cost per hour [€/hour]

dist: average length of the line [km]

seats: average number of seats of rolling stock [seats]

time: average duration of the service [hours]

energy: cost of energy, obtained by IM and added ex-post

In the following paragraphs, we will detail how the above coefficients k0-k3 have been estimated.

Intercity segment [CONFIDENTIAL]

[omissis]

Regional segment

Despite regulated and subject to PSO and subsidised, the regional segment does not enjoy a similar transparency in regulatory accountability, or at least it was not made available to this study. The estimation provided is based on extremely aggregate data for a subset of regions. The numerosity of the data and its detail was not sufficient to perform any statistical calculations, so our estimation is an *educated guess* that broadly fits with the available aggregate observations.[7] The estimations can be updated if data with the required detail is provided by RUs.

---

[5] The timetable structure is often ignored in determining costs but is actually relevant because influencing both the use of rolling stock and of personnel. For example, consider a line with 20' of running time and 10' of tournaround time at terminal. That line can be operated with one crew and one trainset and providing a clock faced service every hour. If for some reasons that line is running every 2h instead of every hour, the actual total costs are not halved because personnel is inefficiently used. Just distance-related costs are halved (e.g. energy consumption, amortisation, part of the maintenance), while others are just reduced or even constant (e.g. personnel cost, fixed costs, etc.). The one above is a specific case, but in general we can affirm that, if supply is reduced by a factor of X, costs are not reduced by the same factor unless specific conditions are met (for a complete discussion, see Ciuffini, 2001).

[6] The impossibility to use a cost function reflecting also timetable structure is particularly hard to apply also because the timetable optimisation is not done at the line-level, but may involve more lines. E.g. the idle time of the example in note [5] might actually be used on another line.

[7] We analysed in deep also the so-called "Standard costs", a statistical study performed by the "Osservatorio nazionale per le politiche del TPL" operating inside the Ministry of Transport and transferred into the Ministerial Decree 157/2018. The outcome functions of that study are however not useful for our purposes, because based on a € per seatkm basis and not on a trainkm basis. In other words, applying the functions to a train with 100 seats

Starting from aggregate data of Table 4, we adopted an approach similar to Intercity segment, but with less cost drivers (Table 5).

Table 4. Production cost of a selection of regional contracts.

Production costs [M€/2022]	Friuli VG	Marche	Umbria	Toscana	Lazio	Campania	Puglia	Calabria	Sicilia
TAC	-20,0	-11,6	-13,5	-78,6	-71,4	-38,1	-16,6	-15,3	-25,7
Circulation	-5,7	-2,4	-1,5	-17,1	-18,1	-10,8	-7,5	-2,1	-5,6
On board personnel	-18,7	-14,8	-13,3	-90,3	-83,4	-55,6	-22,0	-23,2	-45,6
Manouver	-2,4	-1,5	-0,4	-7,8	-4,5	-4,2	-2,9	-2,8	-5,5
Maintenance	-13,6	-4,2	-8,2	-41,3	-40,0	-29,9	-12,4	-13,4	-21,5
Cleaning	-4,6	-2,6	-1,8	-13,5	-13,9	-7,0	-4,0	-2,8	-6,2
Commercial costs	-6,0	-2,4	-1,3	-18,1	-24,2	-9,9	-4,5	-4,3	-5,5
Staff costs	-7,7	-6,5	-4,1	-23,2	-22,0	-17,9	-9,2	-13,1	-14,2
Amortisation	-15,9	-21,6	-13,9	-91,0	-87,2	-37,9	-15,5	-20,1	-27,2

Table 5. Drivers and estimated KPI of regional contracts.

Production costs [M€/2022]	KPI	Component
TAC	Trainskm (access)	Fixed
Circulation	Hours	Fixed
On board personnel	Hours	Fixed
Manouver	Number of trains	Variable
Maintenance	Trainskm	Variable
Cleaning	Trainskm	Variable
Commercial costs	Seatskm	Variable
Staff costs	Number of trains	Fixed
Amortisation	Trainskm	Fixed

To estimate the coefficients k of the previous function, we computed unitary costs (€/train, €/trainkm, €/hour, €/seatkm) and determined the mix of rolling stock types by region. Unfortunately, unitary costs are quite different, and the differences are not explainable only with the mix of rolling stock: other factors matter, such as the presence or not in the contract of a guarantee in rolling stock age or regional contributions for investments, but these factors are not controlled. Consequently, the coefficients of Table 6 are estimated in a qualitative way.

---

gives exactly the half of the cost per km of a train with 200 seats. Therefore, this estimation is usable, at best, for aggregate statistical purposes and not for the estimation of the costs of a line or of a single train service.

Table 6. Cost coefficients' estimations for REG segment, excluding energy.

group	Rolling stock	k0	k1	k2	k3	fixed part
R	loco E464	120	6	0,0010	260	74%
R	loco D445	120	6	0,001	260	74%
R	loco	120	6	0,001	260	74%
R	ALe	150	7,5	0,003	270	74%
R	ALn	350	3,5	0,0055	200	74%
R	EMU reg small	190	7	0,002	200	74%
R	EMU reg high capacity	190	7	0,002	200	74%

Nevertheless, re-applying to all lines present in the database the estimated cost functions, we obtain the trend of unitary costs per commercial speed represented in Figure 9, that can be used for validation.

Total operating cost REG trains (incl. amortisation, excl. TAC)

$$y = 252{,}52x^{-0{,}711}$$
$$R^2 = 0{,}4236$$
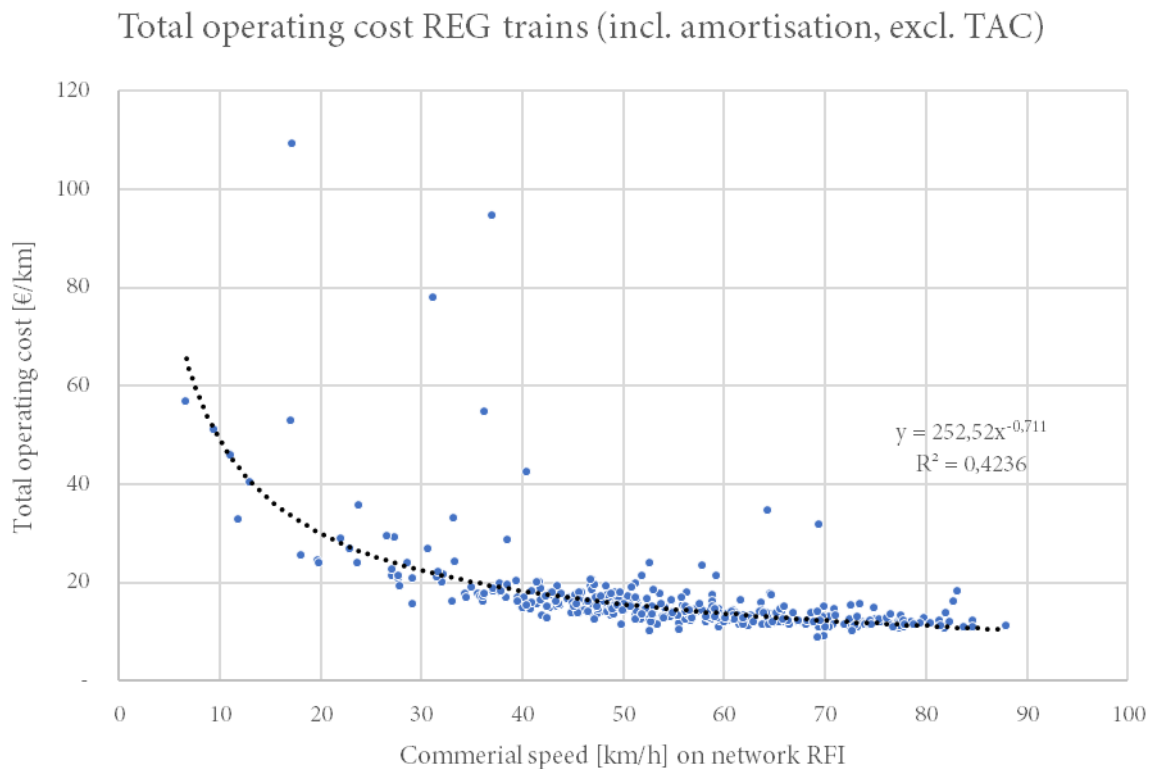
Figure 9. Application of estimated cost functions for REG trains to the lines of the database.

Open-access segment

During consultations no RU provided data concerning the cost structure of the open-access market segment. Moreover, the financial statements published for the two main Italian operators are barely usable for our purposes:

- Italo/NTV Spa's last financial statement dates back to 2021 (AIDA Bureau van Dijk) or 2020 (published, including the accompanying text), during the Covid-19 crisis. For this reason, we referred to 2019 one.
- Trenitalia's financial statement is, since 2019, is no more available, as all financial information are included in the consolidated financial statement of the holding company, Ferrovie dello Stato Italiane, which includes also owned companies operating out of Italy, like Netinera Deutschland GMBH or Hellenic Train S.A. This double aggregation, by country and by transport segment, does not allow to rely on usable cost estimates of the Italian long-distance open access segment only.

In a total absence of any reliable data, we defined the usual cost function coefficients for Italo/NTV as the average values that multiplied by trainskm and trainsh reproduce the total costs of the Financial Statement 2019. Double composition trains have the same per hour cost and a double per km cost. For Trenitalia *Frecciarossa* and *Frecciargento* we increased the costs of Italo by approx. 20%. For *Frecciabianca* we differentiated the estimation according to the rolling stock: if loco rolling stock, we used the same values of ICs. For *Frecciabianca* trains using old HS rolling stock we decreased the per km component and left the same per hour component of *Frecciarossa*. Coefficients are reported in Table 7 and can be improved during consultation if documented cost data is made available by RUs.

Table 7. Cost coefficients adopted for Open Access segment, excluding energy.

RU	*group*	*Rolling stock*	*Composition*	*k0**	*k1*	*k2**	*k3*	*fixed part*
TI	FB	loco E464	single	980	11,636	0,0013	626	74%
TI	FB	loco E464	double	980	13,022	-0,0003	626	74%
TI	FB	loco	single	1380	7,3595	0,0267	392	74%
TI	FB	loco	double	1380	5,7033	0,0201	392	74%
TI	FA	HS	single	1	12	0	500	75%
TI	FA	HS	double	1	24	0	500	75%
TI	FB	HS	single	1	8	0	500	75%
TI	FB	HS	double	1	8	0	500	75%
TI	FR	HS	single	1	12	0	500	75%
TI	FR	HS	double	1	24	0	500	75%
ITALO	italo	HS	single	1	10	0	445	75%
ITALO	italo	HS	double	1	20	0	445	75%

*: Due to lack of detailed data, the estimation for HS segment is more rough and does not include any event driven and seats driven cost. To maintain the same function, their coefficients have ben put to 1 and 0 to make their contribution irrelevant.

Calculation of incidence of TAC on total operating costs

For the costs' side, we apply the functions previously determined for the two prevalent types of rolling stock used, weighting them to obtain the total cost of the line expressed in €/year. The above cost functions do not include energy, that is added on a per km basis for each line, using the detailed (by train) data provided by the IM.

This passage allows to calculate the **incidence of the toll on total costs** (Figure 10 reports the results of the simulations). The incidence is used to express the total cost C_1 at t=1 in function of the old and new tolls, which is one of the steps of the modelling (block 1 of Figure 8). The following formula is adimensionalised (C_0=1) for the reasons that will be explained later in 2.3.3:

$$C_1 = \text{adimensional total cost} = 1 + x \,(tac_1/\, tac_0 - 1)$$

with: x = incidence of access charge on total costs = $tac_0/(\text{unit\_cost\_including\_energy}_0 + tac_0)$

For example, if the production cost of a line is 18,48 €/km, plus 4,55 €/km of tolls, x=19,8%. If the toll is increased by 10%, the total cost at t=1 will be 1,98% higher. Consequently, in the adimensional cost C, passes from 1 to C_1=1,0198.
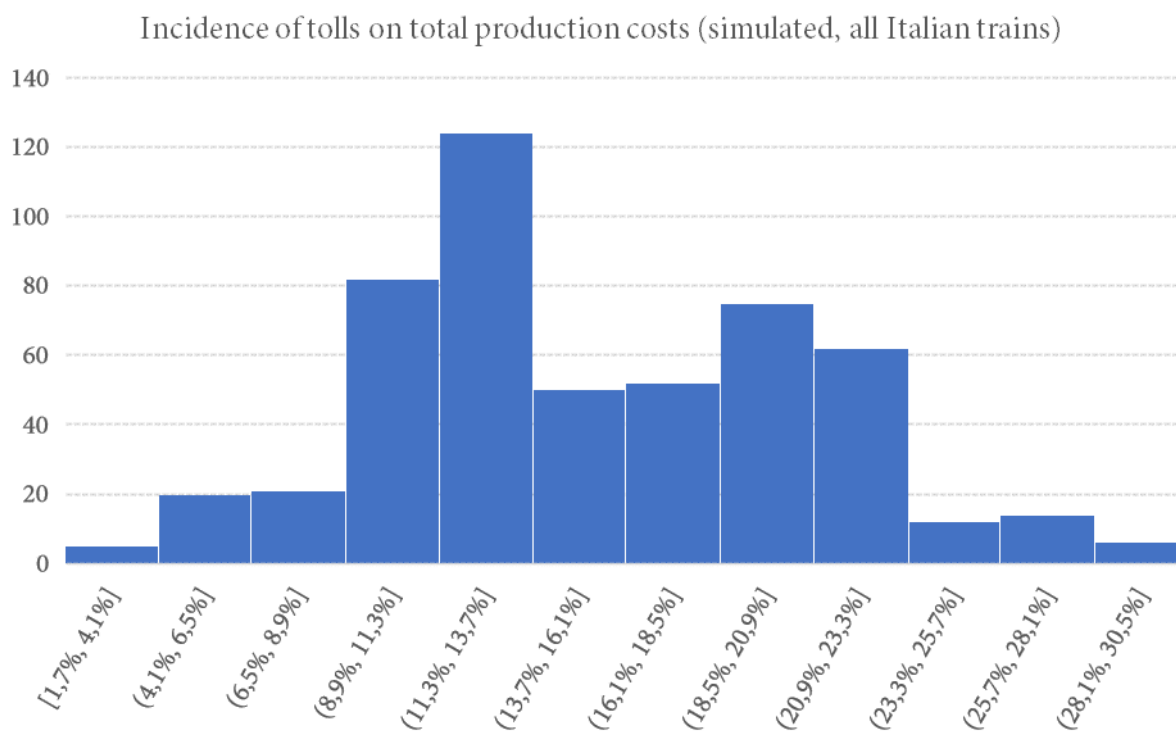
Figure 10. Simulated incidence of tolls (TAC) over total production costs, per line.

2.3.2 Transport model and users' elasticities

One of the main "bricks" of the modelling exercise is the sub-step 2 which determines how final demand of passengers responds to the variation of the main service parameters. The parameters can be many, but, in this case, we limit to those that can be properly modelled at the national scale: fares and frequency of services.

We described the main features of the transport model in Section 5; here we describe the procedure used to estimate the elasticities.

The transport model i-TraM has been calibrated ad hoc using 2019 data. Once calibrated, the model is fed with the timetable and observed prices of 2022, which is the **state-of-the-art scenario**. Then, we run new scenarios in which:

a. Fares of train services increase of 5%
b. Fares of train services decrease of 5%
c. Frequency of train services increase of 5% (i.e. waiting time decrease of 5%)
d. Frequency of train services decrease of 5% (i.e. waiting time increase of 5%).

The level of 5% have been chosen considering that the likely modifications should be of this size and not more, given the limited impact of TACs on costs and the expected changes in TACs. The computational burden (in the range of a week of calculations) has not allowed to run more simulations for different percentage changes.

By comparing the demand (in passengerkm) of state of the art and of modified scenario, we can calculate the average elasticities to fare increase, decrease and to frequency increase and decrease, as in the example.

Line	SDF22	TTm1	delta	e_Pax(fare+)
[omissis]	357.667	377.493	19.826	**-1,11**

The formula, of course applied to different simulations, is simply:

$$\varepsilon_D(\text{fare}) = \varepsilon_D(\text{freq}) = ((D_1 - D_0) / D_0) / 0{,}05$$

The simultaneous variations of all trains fares or frequencies may generate cross-elasticities. For example, rising the prices of HS and IC may make relatively more convenient the IC, whose direct elasticity is to price less negative than if we considered the IC service alone. This problem has been corrected by running separate simulations for groups of services (fast, conventional and regional) and in a handful of cases fixed manually by analogy with similar lines.[8]

The results are reported in Table 8 and Table 9, grouped by train classes (as described by i-TraM) and by market segments (of the previous regulatory period), respectively.

Table 8. Average elasticities estimations of passengerkm to fares and frequency, simulated year 2022, by train type. Source: our elaborations on i-TraM (META/TRASPOL).

Average Pkm elasticity to:	Fares		Frequency	
	5%	-5%	5%	-5%
Fast trains	-1,28	-1,24	0,06	0,04
Conventional trains	-1,76	-1,73	0,12	0,09
RegioExpress	-0,28	-0,30	0,18	0,16
Regio	-0,24	-0,25	0,20	0,17
SBahn	-0,24	-0,26	0,18	0,16

Table 9. Average elasticities estimations of passengerkm to fares and frequency, simulated year 2022, by market segment. Source: our elaborations on i-TraM (META/TRASPOL).

Average Pkm elasticity to:	Fares		Frequency	
	5%	-5%	5%	-5%
1.2 Open Access - Nazionali - Premium - Top	-1,23	-1,20	0,04	0,03
1.6 Open Access - Nazionali - Premium - P-base	-1,15	-1,14	0,09	0,05
1.8 Open Access - Nazionali - Premium - P-light	-1,70	-1,54	0,06	0,04
3.1 Open Access - Nazionali - Basic	-1,76	-1,72	0,10	0,08
4.2 OSP - LP - Giorno	-1,78	-1,77	0,16	0,14
5.1 OSP - REG - Nodo Hub-Sprint	-0,30	-0,33	0,17	0,15
5.2 OSP - REG - Nodo Hub	-0,26	-0,27	0,19	0,17
5.4 OSP - REG - Nodo Ring	-0,26	-0,27	0,19	0,17
5.6 OSP - REG - No Nodo	-0,23	-0,24	0,21	0,19

The most sensitive trains to fares are conventional services (both OA Basic and OSP Intercity), with average ε bigger than -1,5. The Premium Top segment is less elastic but still larger than -1. This is due to the fact that the price is a large component of generalised cost, especially for the faster services or for short trips on other long-haul trains. Also, Premium services run at very high load factors, meaning that some travellers might be excluded by fare system. And in fact, such a high elasticity means that there is still potential demand (from other modes in particular, including car) unexploited if prices decrease. For the IC segment the reason for such a high elasticity is competition with coaches and regional trains and high price-sensitivity of OSP users.

---

[8] While it is wrong to simulate a simultaneous price increase for all trains because of cross-elasticities, it is also not correct (and requiring months of computations) to simulate the effect on one single mission, moreover if we refer to regional trains which are not prices on a single line basis.

The most rigid to prices services are instead the regional ones, with limited distinctions by market segment but some differences by product, with RegioExpress slightly more elastic[9]. Low elasticity of regional services derives from low price levels and high share of captive demand.

Elasticity to frequency is much lower. The relationships between fast and regional services are inverted: regionals are the most sensitive to frequency (which makes sense), while HS trains the least (which is due to the extremely high frequencies of the recent timetables: any marginal increase or decrease of frequency is basically irrelevant for demand).

The model gives a certain heterogeneity among single lines, as depicted in the following figures from Figure 11 to Figure 20. Some outliers with elasticities higher than -2 have been capped to avoid overoptimism in passenger's response. All signs are coherent: positive for frequency and negative for fares. The largest heterogeneity is observed among long-distance services, where the competitive conditions are very differentiated (some are in competition with air, other with coach/road, other are not in competition. Moreover, some lines are under intermodal competition and others no). The effect of frequency is, as already commented, small and concentrated, but more relevant for shorter distances. For regional trains we observe just some outliers, whose size in terms of paxkm is extremely limited and thus irrelevant for the overall results.

---

[9] Probably because of a slightly higher share of fares into generalised cost.

Figure 11. Distribution of elasticity to fares. Fast train segment

Figure 12. Distribution of elasticity to frequency. Fast train segment

Figure 13. Distribution of elasticity to fares. Conventional trains segment
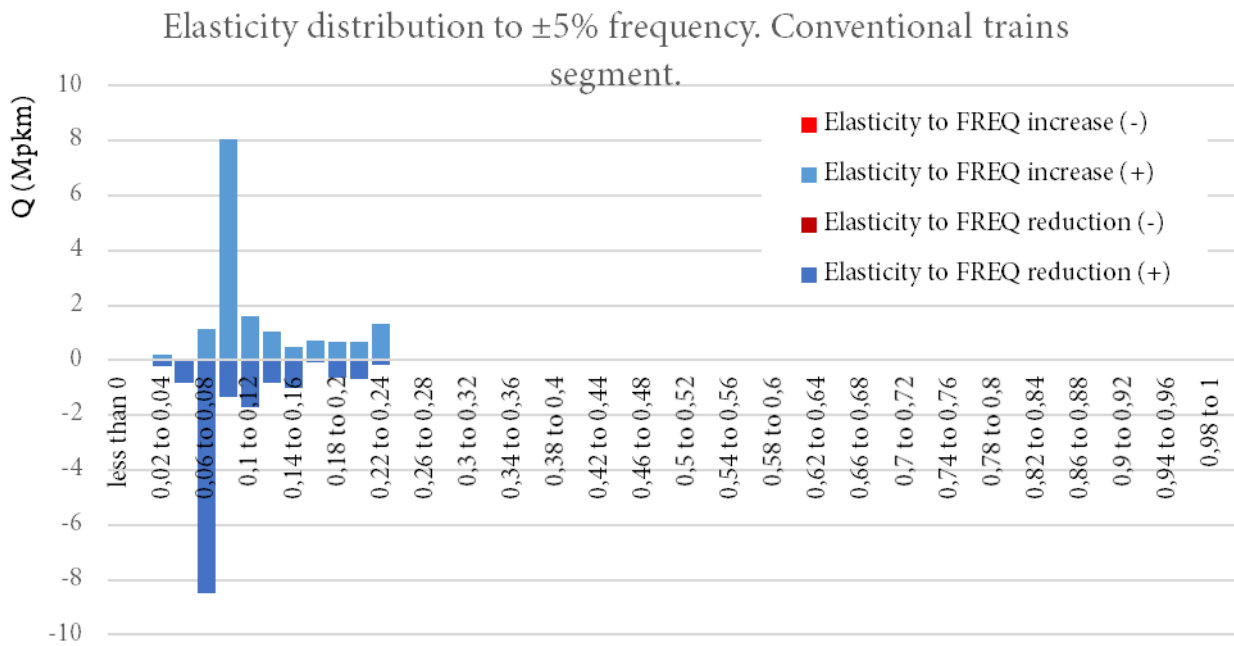
Figure 14. Distribution of elasticity to frequency. Conventional trains segment
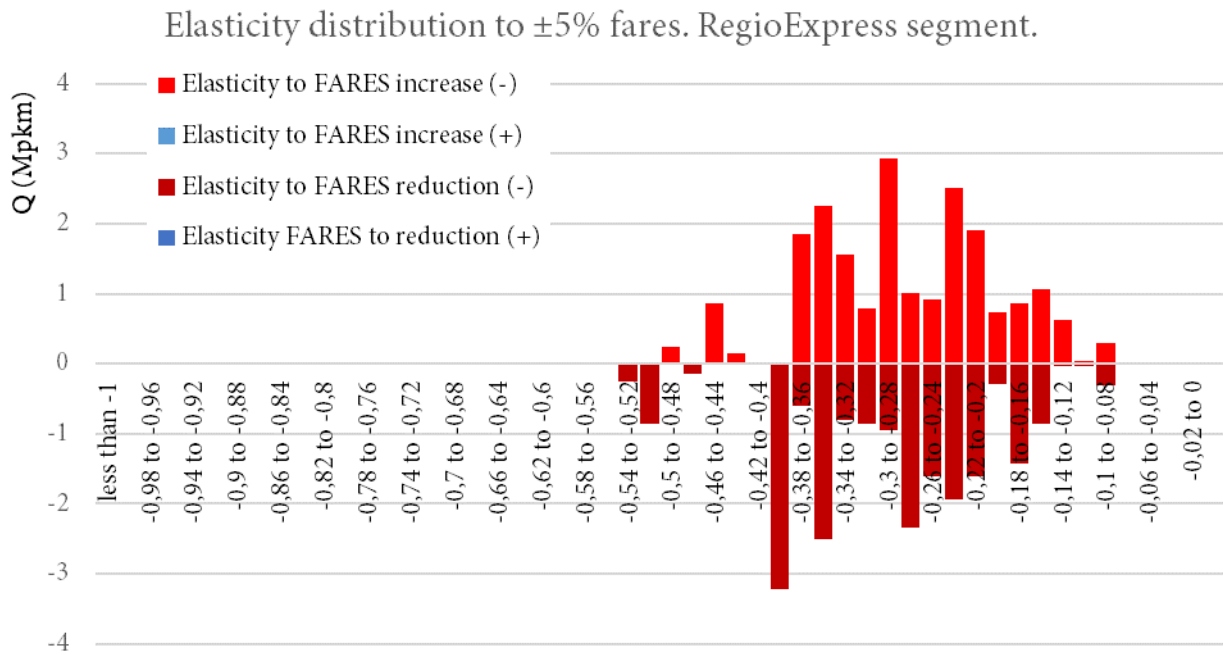
Figure 15. Distribution of elasticity to fares. Regioexpress segment
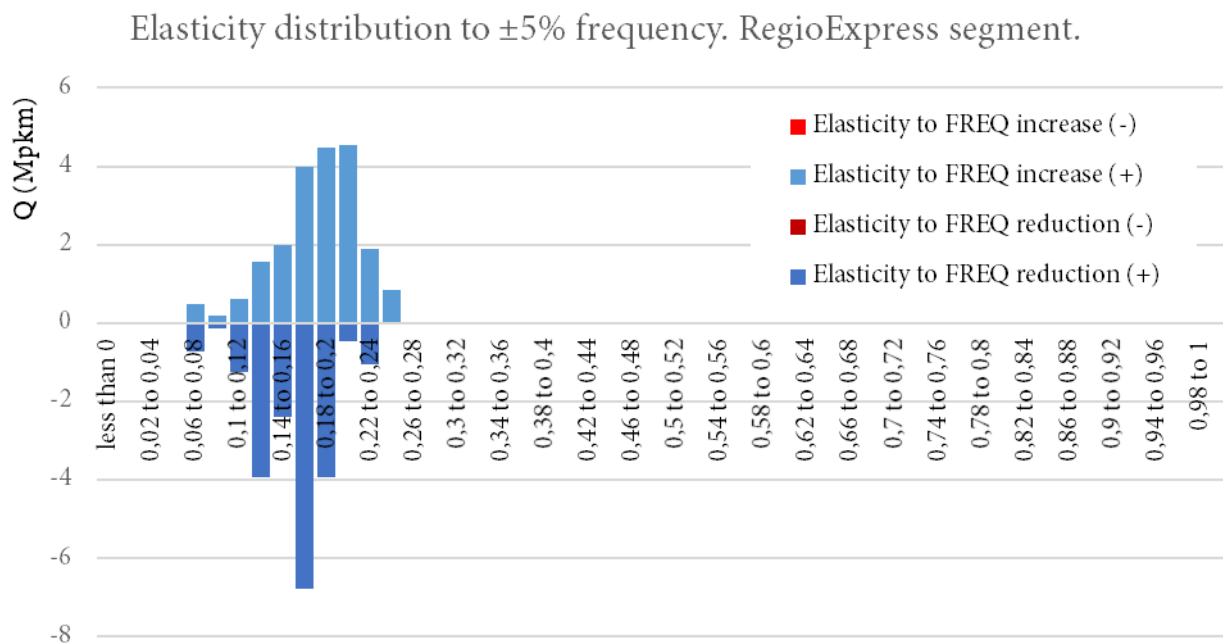
Figure 16. Distribution of elasticity to frequency. Regioexpress segment
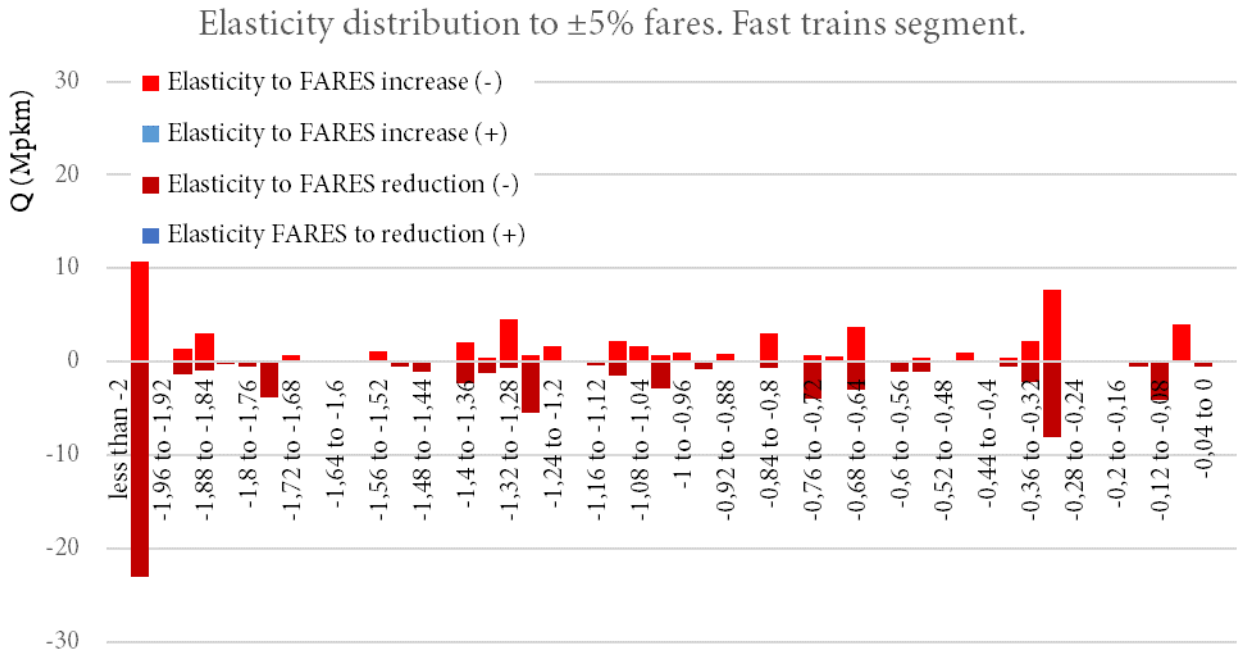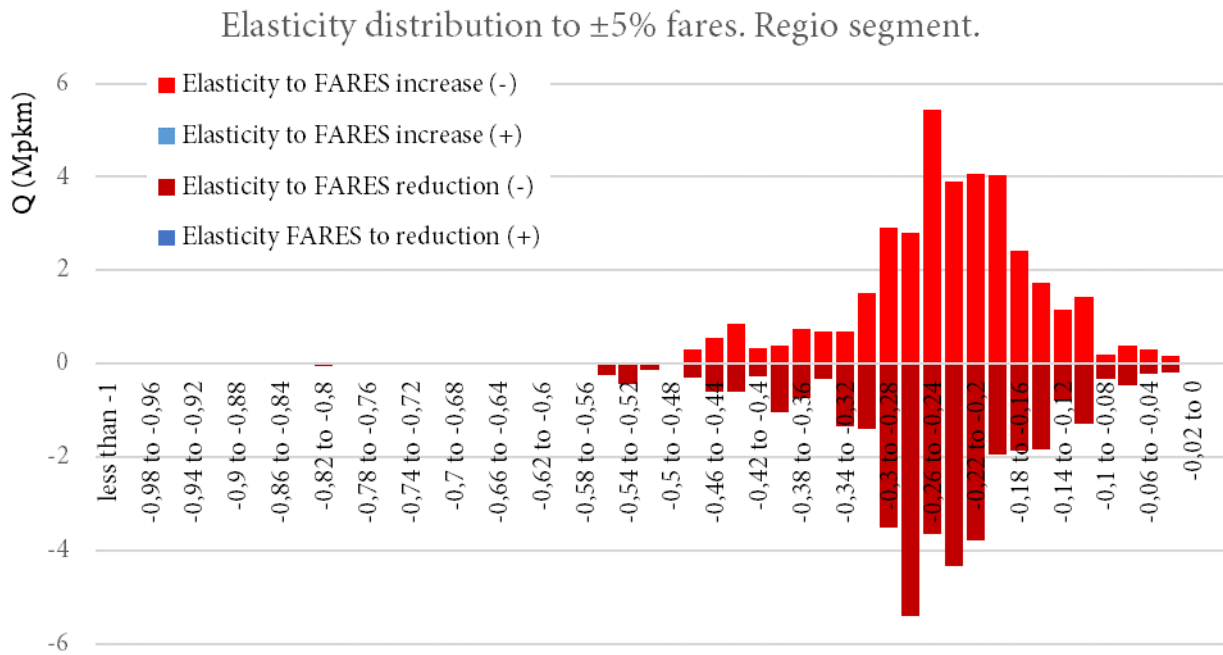
Figure 17. Distribution of elasticity to fares. Regional trains segment
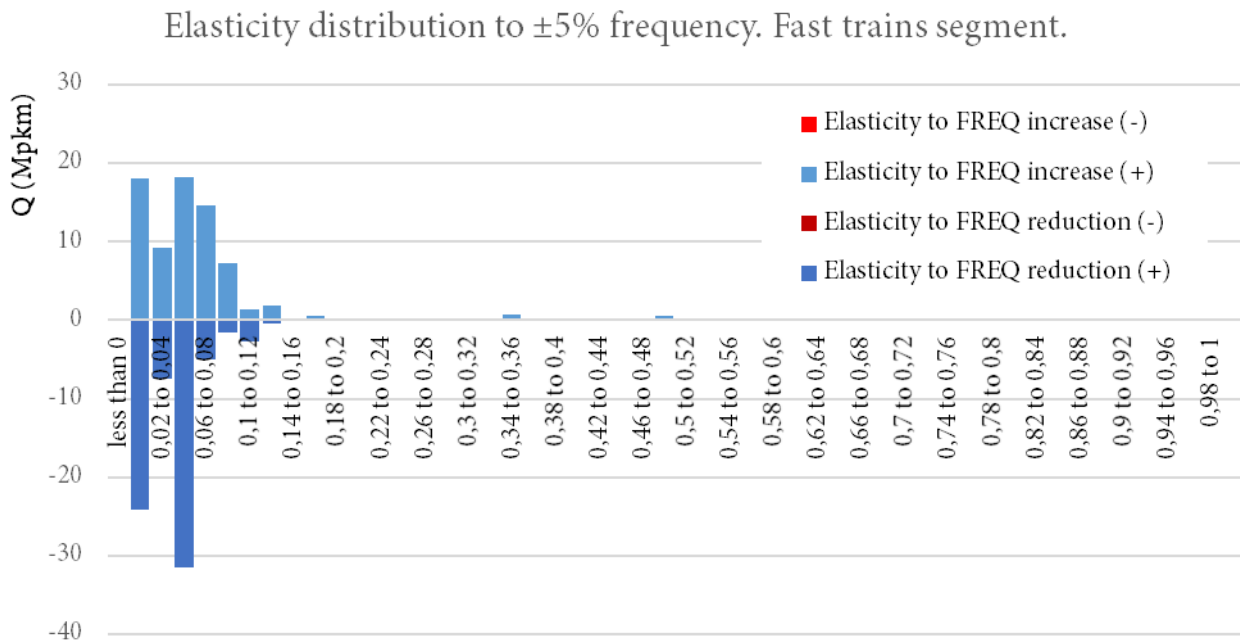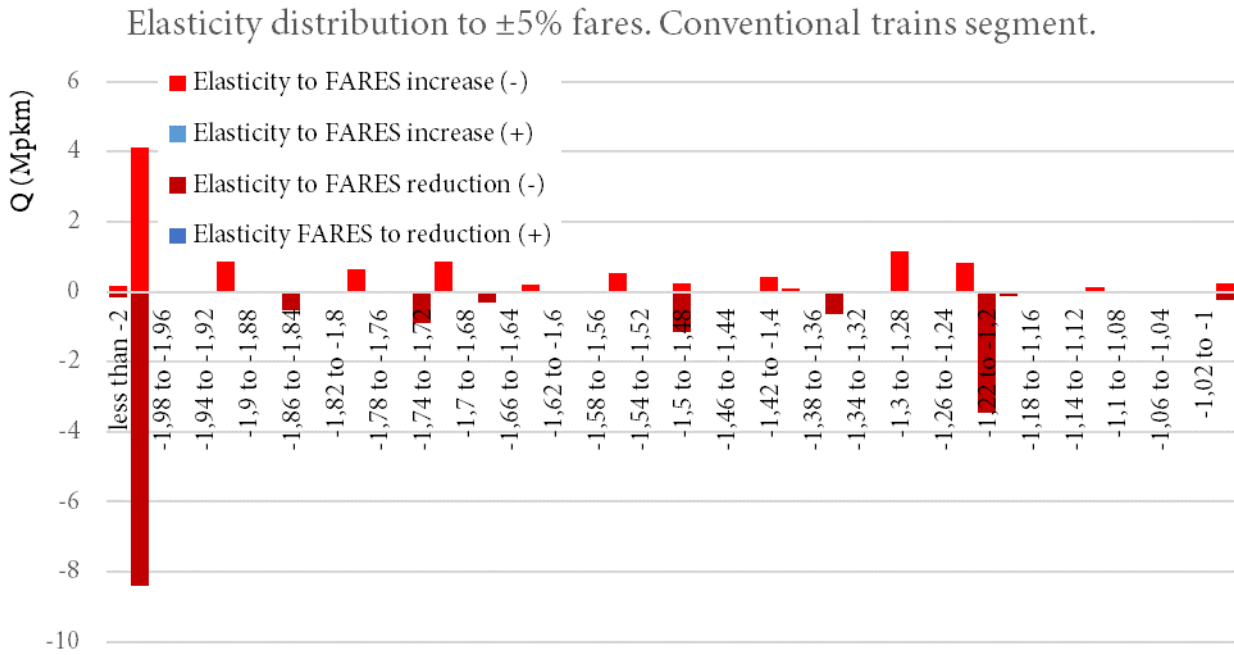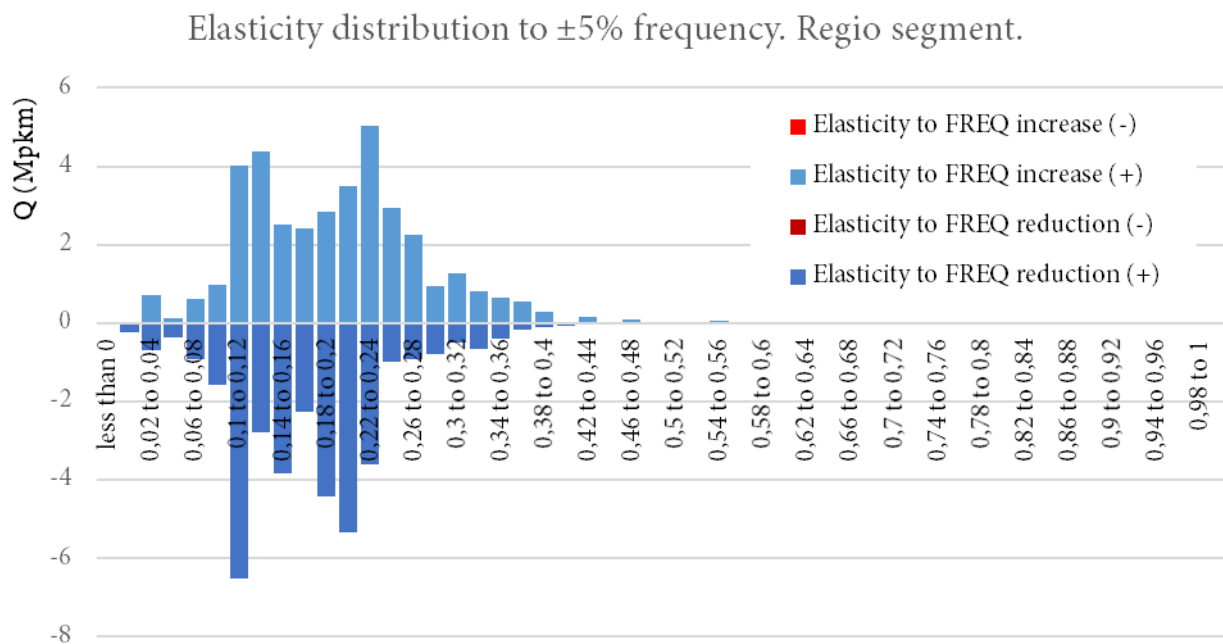

Figure 18. Distribution of elasticity to frequency. Regional trains segment
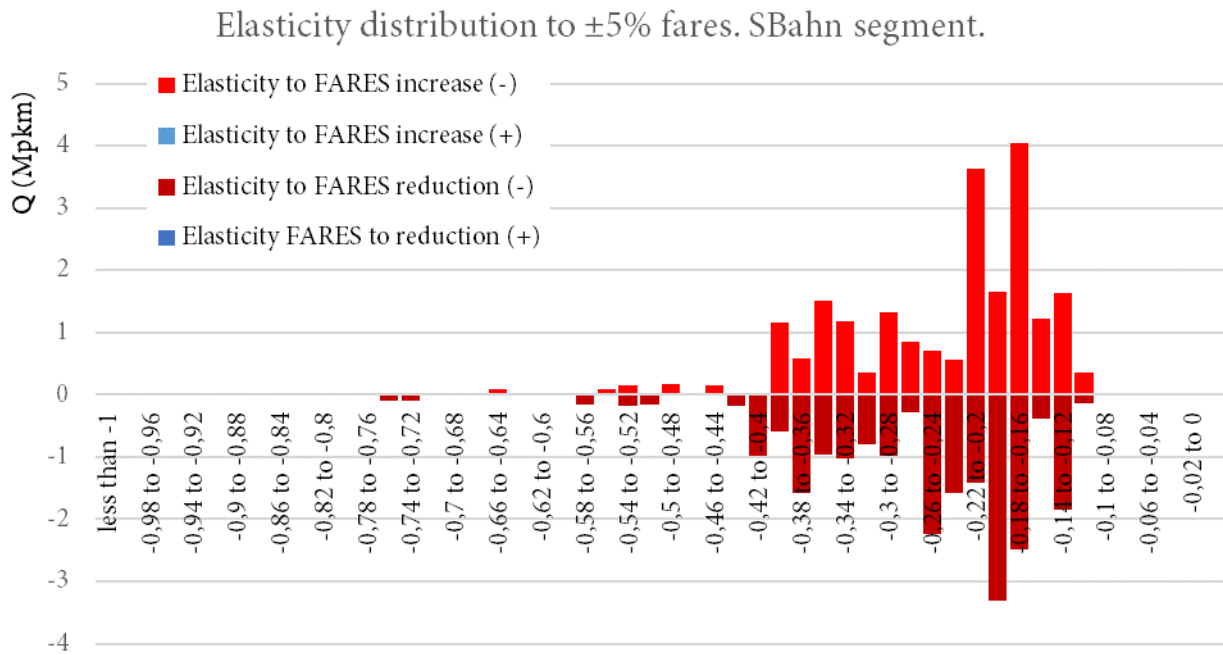
Figure 19. Distribution of elasticity to fares. Suburban trains segment
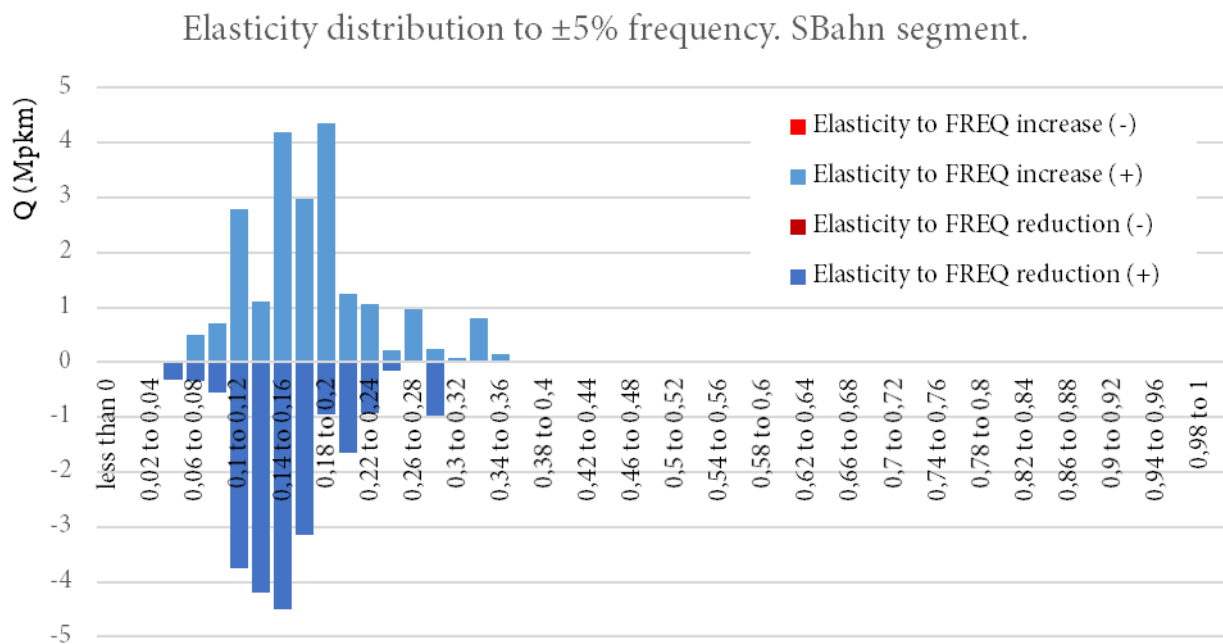
Figure 20. Distribution of elasticity to frequency. Suburban trains segment

In conclusion, the overall simulation looks very convincing both looking at averages and on single cases. Nevertheless, some limits must be pointed out.

Firstly, despite having ran separate simulations for different service groups, the problem of cross-redistributions remains especially for frequency simulations due to their small effect. For example, reducing the frequency of all regional trains generates a shift to private car, but also a second-order shift from slower to faster lines. To avoid redistributions among lines but keeping modal shift, the project (i.e. the varied frequency scenario) modal split has been assigned to the state of the art scenario. This operation corrects most of the errors due to cross-elasticities, but makes slightly more rigid the simulations.

A second limit comes from the definition of fares. In absence of a detailed OD matrix of fares, some corrections can be applied to single lines (see section 5.4.2) that deviate from the average prices of a

segment/company. These corrections, when negative, generate an "artificial" attraction to these lines also in the core segments. For example, the prices Rome-Bolzano were lower, per km thresholds, than Rome-Milan. However, in reality, for Rome-Bologna passengers, the train is the same and most likely also the fares. To avoid overloading marginal lines, we preferred to use prices coherent with those of the core section of the network, probably resulting in lower simulated demand on some legs (e.g. to correctly simulate the central section of the HS line, the prices of passengers from Bolzano to Rome are higher, making that relation less attractive than in reality. The solution would be to input a detailed OD matrix of fares, which is however unavailable.

2.3.3   Simplified RUs behavioural model

The simulation of how the RU, or the Planner (Regional Governments and MIT), reacts to the variation of unit tolls is not only crucial for the overall elasticity estimation, but also an extremely complex task characterised by a severe information asymmetry. In fact, we must acknowledge that the drivers of stakeholders' behaviours are not limited to the price, but are many other and hard to model, such as:

a.   (The toll);
b.   The size of fixed vs. variable costs;
c.   Possible constraints to the first best (e.g. public service obligations or political wills);
d.   The real options available in terms of industrial organisation (e.g. impossibility to increase capacity for rolling stock shortage);
e.   Coordination between single lines in a network (e.g. need of maintaining network effects);
f.   The alternative use of production factors (e.g. a saved trainkm can be "reused" elsewhere?);
g.   General company strategies (e.g. pushing a line or a product despite the short-term margin).

For example, if tolls rise of 10%, a firm might accept to reduce its margin but keeping the service exactly as it is, since fares are fixed (e.g. because regulated like in intercity services) and/or no reorganisation is reasonable (rolling stock is optimized and slightly reducing the service does not make sense commercially). But this is not the only possible outcome. In another context, e.g. in a monopolistic long-distance market, the enterprise might decide to slightly raise prices (e.g. rising the cheapest discounted fares) if the demand for that line is rigid. However, if the demand is not rigid because of alternatives (e.g. a competitive and cheap bus or air service), rising prices might induce even worse margins, suggesting the opposite option: extend promotional prices and aim at better load factors at the expenses of competitors.

These are of course just examples. In the following, we will describe the modelling approaches used to cope with the problem of forecasting the RU/Region/MIT behaviour to a bidirectional change of access charges.

Two approaches. Scenarios of the TRASPOL/RFI model

Under the practical impossibility to model all the real strategic and tactical choices of the RU, we must abandon a deterministic response of the stakeholder to the variation of tolls, of the kind that can be represented through an elasticity to a set of parameters. To overcome this limit, but to provide ad the same time the needed estimation, we build a stochastic (probabilistic) approach ("TRASPOL/RFI model"), aside to a more deterministic one ("DB model") used for reference. The following table summarises the differences between the two.

Deterministic approach	Probabilistic approach
Q = *f*(tac, **X**) ➔ Q, expressed in *trainskm*, is a univocal function of the train access charge and of **X**, a vector of additional relevant and quantifiable parameters.	$Q = \Sigma\ Q_i \cdot p_i(V_i)$ *i*: scenario *p*: probability of occurrence of *i* scenario. ➔ Q is the "probabilistic quantity" of trainskm, obtained by weighting Q_i with the probability of occurrence of each scenario. ➔ The probability of a scenario depends on a quantifiable and deterministic measure of utility of that scenario.
"DB model" **based on elasticity** of Q(trainskm) to demand.	"TRASPOL/RFI model", **based on a logit model** with the **adimensional margin** of a line (group of missions) as a **proxy of the deterministic utility** of the scenario.

The idea behind this approach, is that the current service is an equilibrium, in which the RU/Region/MIT has found a satisfying level of supply, costs and demand, such that $R_0 = \pi \cdot C_0$, with R_0: total ticket and subsidies revenues of a line at time t=0, C_0: total production costs of a line and π: an unknown mark-up. If a new regulation modifies the tolls, the RU/Region/MIT will modify the supply in a certain way (that is the expected output of this modelling), that in turn will modify the demand and then the revenues. The new situation is characterised by a new equilibrium, that can be "better" or "worse" for the RU/Region/MIT and entails a new level of margin $R_1 - C_1$.

Instead of deciding which is "the" new equilibrium, the **TRASPOL/RFI model** calculates the margin of a number of "scenarios" representing stylised responses to the toll variation, depending on cost level and demand elasticity to price and frequency. Such margins can be either all positive, all negative or a mix of positive and negative according to the single case. The stylised scenarios, resulting from a long definition process, are described in the following Table 10. The translation of the **DB model**, used for reference, consists simply in the application of the sole scenario 2, where fares are modified exactly to compensate total cost changes, in turn due to TAC changes.

Table 10. Scenarios of RU response to TAC changes in the TRASPOL/RFI model.

Scenario	Description	Condition
1	Rigid supply: no change in supply & fares	
2	Fares are modified (+/-) to compensate (C1=C0) production cost changes (+/-), considering revenues/cost ratio	
3	Fares increase of +deltaTAC%	Only if TAC increases
4	Fares decrease of -deltaTAC%	
5	Frequency (trainskm) are modified (+/-) to compensate (C1=C0) production cost changes (-/+)	
6	Frequency (trainskm) modified (+/-) of deltaTAC% in response of production cost change (-/+)	
7	Train capacity increase and corresponding frequency (trainskm) reduction to compensate TAC increase (C1=C0).	Only if TAC increases

8	Train capacity decrease and corresponding frequency (trainskm) increase to compensate costs (C1=C0).	Only if TAC decreases
9	Frequency (trainskm) reduction to compensate extra-costs (C0=C1) and corresponding capacity increase. Fares are reduced in function of extracapacity.	Only if TAC increases
10	Train frequency increase and corresponding capacity decrease to compensate costs (C1=C0). Fares are increased of capacity reduction.	Only if TAC decreases
11	Train capacity increase of +deltaTAC%, but fixed frequency (trainskm).	
12	Train capacity decrease of -deltaTAC%, but fixed frequency (trainskm).	

Calculation of "margin"

For each of the 12 scenarios we can determine the needed margin by calculating sequentially the new costs and the new revenues, **for each line** (i.e. group of homogeneous missions).

It is important to mention that **all margins calculations are done in an adimensional way**. While we can model the cost side (2.3.1) and obtain a €/km figure, **we cannot do the same for revenues**. For this reason, we perform all calculations adimensionally, with $C_0=1$ and $R_0=1$. This simplification is necessary in absence of a calibrated model for revenues, but is acceptable because of the nature of the

Basically, the 12 scenarios consist in a mix of three possible operations, all conducted adimensionally:

1. **When fares change**, the new demand is computed using the demand **elasticity to fares** obtained from iTraM transport model (described in 2.3.2). New demand and new fares determine a new level R_1 of total revenues ($R_1 \neq R_0$).

$$D_{1,fare} = D_0 \cdot \varepsilon_D(fare) - \varepsilon_D(fare) + 1$$

2. **When frequency (trainskm) change**, two operations are done. On the one side, the new demand is computed using the demand **elasticity to frequency** obtained from iTraM transport model. New demand level determines a new level R1 of total revenues ($R_1 \neq R_0$).

$$D_{1,freq} = D_0 \cdot \varepsilon_D(freq) - \varepsilon_D(freq) + 1$$

At the same time, the new cost C1 ($C_1 \neq C_0$) due to trainskm production change is computed considering the **cost functions** described in 2.3.1, but also the fact that a part of the costs are fixed and cannot be modified by the operator.

$$C_{1,freq} = (c \cdot \alpha \cdot Q_0 \cdot fc + c \cdot \alpha \cdot Q_0 \cdot (1-fc) + tac_1 \cdot \alpha \cdot Q_0) / (c+tac_0) \cdot Q_0$$

[Fixed component + variable component modified with frequency + total charges modified with frequency]

With c = unit total production cost [€/km]

fc = fixed cost / total cost

Effect of frequency (trainskm) variation on costs, in presence of fixed costs.

This box discusses how costs are calculated adimensionally through the previous formula $C_{1,freq}$, starting from predetermined cost functions and considering the effect of fixed costs (costs that remain constant also in presence of a variation in supply).

Initial cost = C_0 = industrial fixed cost + industrial variable cost(*freq*) + tac_0

Final cost, fixed cost function = C_1' = industrial fixed cost + industrial variable cost(*freq*) + tac_1

Final cost, general case = C_1 = industrial fixed cost + industrial variable $cost_1$(*freq*) + tac_1

Let's start from a numerical example, with Q = trainskm produced, a share of fixed costs equal to 80%, a production cost of 10,75 €/km and an access charge of 3,24 €/km. With these data, we can compute the total cost at time t=0:

$$C_0 = (10{,}75 \cdot 0{,}8 + 10{,}75 \cdot 0{,}2 + 3{,}24) \cdot Q_0 = 13{,}99 \cdot Q_0$$

At t=1, trainkm production (=frequency) is lowered by the company by 5% ($Q_1 = 0{,}95 \cdot Q_0$) in response of a 10% increase of TAC. The new total cost is:

$$C_1 = 10{,}75 \cdot 0{,}8 \cdot Q_0 + 10{,}75 \cdot 0{,}2 \cdot (0{,}95 \cdot Q_0) + 3{,}24 \cdot 1{,}1 \cdot (0{,}95 \cdot Q_0) = 14{,}02 \cdot Q_0$$

Dividing by Q_0, we adimensionalise the cost, obtaining that the increase of TAC by 10% and the contextual reduction of frequencies by 5%, raises the total RU costs from 1 to 1,002 (+0,2%).

Treating adimensionally the calculation since the beginning, we obtain:

c = total unit industrial costs (variable + fixed), excluding TAC

fc = share of fixed costs

Q_0 = trainskm at t=0 and $Q_1 = Q_0 \cdot \alpha$ trainskm at t=1, reduced (or increased) by factor α.

tac_0 = initial access charge at t=0 and $tac_1 = tac_0 \cdot \beta$ access charge at t=1, increased (or reduced) by a factor β.

With this notation, we can write:

$$C_0 = c \cdot Q_0 \cdot fc + c \cdot Q_0 \cdot (1\text{-}fc) + tac_0 \cdot Q_0$$
$$C_1 = c \cdot Q_0 \cdot fc + c \cdot Q_0 \cdot \alpha \cdot (1\text{-}fc) + tac_0 \cdot \beta \cdot Q_0 \cdot \alpha$$

And the needed relative variation of costs due to variation of tolls, used in the main text:

$$\mathbf{C_1/C_0} = (c \cdot fc + c \cdot \alpha \cdot (1\text{-}fc) + tac_0 \cdot \beta \cdot \alpha) / (c + tac_0) = \mathbf{(c \cdot fc + c \cdot \alpha \cdot (1\text{-}fc) + tac_1 \cdot \alpha) / (c + tac_0)}$$

3. **When train capacity changes**, the new cost C1 (C1≠C0) due to trainskm production change and/or to a different unit cost of rolling stock is computed considering the **cost functions** described in 2.3.1.

Actually, we can produce a more general version of the formula, embedding also the cost effect of a different number of seats/convoy. In other words, the cost per km *c* could vary in function of the number of seats (*K*) of trainsets through an elasticity *εC(seats)*:

$$\mathbf{C_1/C_0 = ((c \cdot fc + c \cdot \alpha \cdot (1\text{-}fc) + tac_1 \cdot \alpha) \ / \ (c + tac_0)) \cdot (K_1/K_0 \cdot \varepsilon C(seats) - \varepsilon C(seats) + 1)}$$

We can finally compute the overall demand effect D_1 as $D_{1,fare} \cdot D_{1,freq}$ and from that the adimensional revenues R_1 taking into consideration that there could not be a total matching between the costs and revenues.

$$R_1 = (1 - k) + (k \cdot D_1 \cdot fare_1)$$

With: *k = margin of contribution*, a sort of revenues cost ratio.[10]

In this way, for every scenario, we obtain an adimensional measure of total revenues and total costs:

---

[10] The *ratio of contribution* is 100% if all revenues come from fares, less than 100% if the service is contributed. It is not exactly the revenues/cost ratio because the RU may obtain a profit, which means that normally revenues must be more than 100% of costs.

$$C_1 \neq C_0 = 1$$
$$R_1 \neq R_0 = 1$$

For example, in scenario 1, $R_0 = R_1 = 1$ because it is assumed that nothing changes for the travellers, while C_1 is more than 1 if tolls increase (for example 1,02 if tolls increase of 10% but represent just the 20% of production costs) and less than 1 is tolls decrease.

The "margin" at t=0 is by definition equal to 0 because in the adimensonal formulation, $C_0 = 1$ and $R_0 = 1$. The margin at time t=1, instead, can now be computed by a simple algebraical sum.

This procedure is repeated for each of the 12 scenarios, whose coefficients expressing the parameter (fare, frequency or seats) at t=1 with respect to t=0 are summarised in the following Table 11, obtaining 12 estimations of margins. As stated above, the margin of each scenario could be negative or positive and the choice of which scenarios are more or less likely to occur is left to the following paragraph.

Table 11. Summary of coefficients of fares, frequency and trainset capacity at t=1 with respect to t=0 used in the simulations.

Scenario	Description	Coefficients		
		Fares	Frequency (tkm)	Seats capacity
1	Rigid supply: no change in supply & fares	1	1	1
2	Fares are modified (+/-) to compensate (C1=C0) production cost changes (+/-), considering revenues/cost ratio	f(R/C)	1	1
3	Fares increase of +deltaTAC%	1+|deltaTAC%|	1	1
4	Fares decrease of -deltaTAC%	1-|deltaTAC%|	1	1
5	Frequency (trainskm) are modified (+/-) to compensate (C1=C0) production cost changes (-/+)	1	f(FC)	1
6	Frequency (trainskm) modified (+/-) of deltaTAC% in response of production cost change (-/+)	1	1-deltaTAC%	1
7	Train capacity increase and corresponding frequency (trainskm) reduction to compensate TAC increase (C1=C0).	1	f(FC)	1/frequency
8	Train capacity decrease and corresponding frequency (trainskm) increase to compensate costs (C1=C0).	1	f(FC)	1/frequency
9	Frequency (trainskm) reduction to compensate extra-costs (C0=C1) and corresponding capacity increase. Fares are reduced in function of extracapacity.	1/capacity	f(FC)	1/frequency
10	Train frequency increase and corresponding capacity decrease to compensate costs (C1=C0). Fares are increased of capacity reduction.	1/capacity	f(FC)	1/frequency
11	Train capacity increase of +deltaTAC%, but fixed frequency (trainskm).	1	1	1+|deltaTAC%|
12	Train capacity decrease of -deltaTAC%, but fixed frequency (trainskm).	1	1	1-|deltaTAC%|

R/C: cost coverage ability, 100% for market services and revenues cost ratio for subsidised services. *FC*: fixed cost. *deltaTAC*: increase or decrease of TAC of the scenario.

Logit *choice modelling*

The choice of RU/Region/MIT among the stylised scenarios is performed through a standard *logit model*. The logit model is the commonest discrete choice model and is used here in the multinomial form, i.e. allowing not only binary choices. The multinomial logit models used in transport economics work estimating the probability of a choice from the utility of the choice itself compared with the utility of the other options. The logit model gives back a non-linear distribution of probabilities, whose shape depends on a set of parameters. In simple terms, the parameters of the utility function determine how "extreme" is a choice, from an "all-or-nothing" model (100% of probability of the option with the highest utility, with a parameter k=infinite) to a homogeneous result (a *1/n* probability for each of the *n* alternatives, with a parameter k=0), as depicted in Figure 21.

As anticipated, we chose the "margin" of the RU/Region/MIT at t=1 as the variable representing the utility. The model will point out as more likely the scenario with the highest margin (or the least negative margin if all scenarios are negative). It is important to underline that the logit models work on the absolute differences between utilities. So, a case with V1=100 and V2=101 will give exactly the same result of a case with V1=1 and V2=2 or V1=-2 and V2=-1, because the difference is always equal to 1. This apparent limit (that is managed through calibration) let us to ignore whether the margin at t=0 is "really" zero, because what matters is the difference between costs and revenues at t=1, whatever is the initial level of C and R.
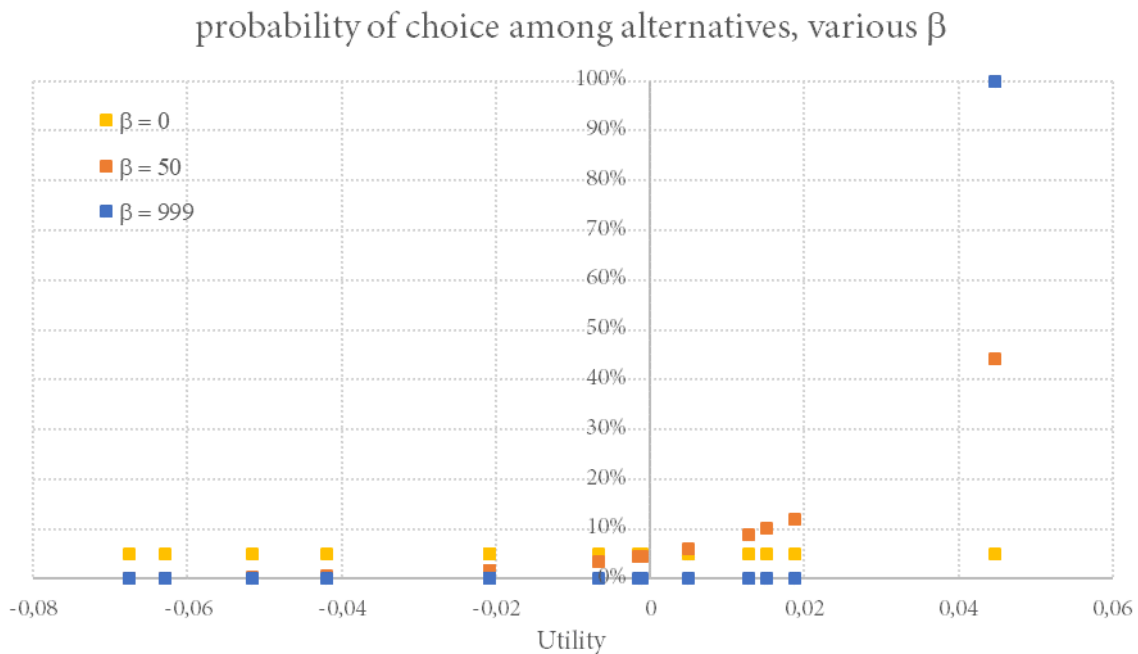
Figure 21. Example of logit model results in function of the calibration parameter β.

The formula applied in the choice model is the following, giving back the probability of occurrence of scenario *i*. The calibration parameter is set to **70** (market segments) or **100** (regulated segments), but it can be modified during the consultation phase to better fit RU choices.

$$p_i = \exp(k \cdot M_i) / \Sigma_j \exp(k \cdot M_j)$$
$$\text{with: } M_i = \text{margin of the } i \text{ scenario} = R_{1,i} - C_{1,i}$$

Actually, the mechanical application of the logit to all scenarios may give unrealistic results. For example, if TAC is reduced, there is no reason for the RU to rise consumers' prices. In fact, an increase of consumers' price, if worthwhile, could have been done irrespectively of the TAC reduction. For this reason, we add a further filter to logit in addition to the conditions to those of Table 10. We call these sets of conditions "rules", that that consist in inhibiting some of the scenarios and that can be applied to each line according to market condition. Rules are described in Table 12 and Figure 22.

Table 12. Description of the *logit* rules

Rule	Description
REG fixed fare	REG trains cannot change Fare, just Capacity and Frequency
REG constrained freq	REG trains cannot change Fare, nor reducing the Freqency more than the increase of cost. Only Capacity and Frequency can vary

REG constrained freq and saturation	Like "REG **constrained** freq", but impossible to increase the frequenct due to network saturation. Freq can only be reduced. Capacity freely variable
REG variable fares	REG trains cannot reduce the Freqency more than the increase of cost. Only Capacity and Fares can change.
REG increased subsidies	Like "REG constrained freq", but Frequency fixed and consequent increase of RU costs (and needed contribution)
MKT base	Market segment: RU can vary any parameter
MKT saturated	Line saturated: frequency cannot be increased, just reduced. Prices and capacity can vary.
MKT Cournot[11]	Service in competition (à la Cournot): frequency cannot decrease, only Price and Capacity can vary
MKT Cournot saturation	Service in competition. Freq cannot decrease (comp. à la Cournot), nor increase (because line saturation). Only Price and Capacity can vary
IC base	Being under PSO, in the short-term Freq is fixed and Fares free. Capacity can vary, too.
IC constrained	Being under PSO, in the short-term Freq can vary just to cover extra-costs. Capacity can vary, too.

rule name	REG fixed fare	REG constrained freq	REG constrained freq and saturation	REG variable fares	REG increased subsidies	MKT base	MKT saturated	MKT Cournot	MKT Cournot saturation	IC base	IC constrained
description	REG trains cannot change Fare, just Capacity and Frequency	REG trains cannot change the Freqency more than the increase of cost. Only Capacity and Frequency can vary	Like "REG constrained freq", but impossible to increase the frequenct due to network saturation. Freq can only be reduced. Capacity freely variable	REG trains cannot reduce the Freqency more than the increase of cost. Only Capacity and Fares can change.	Like "REG constrained freq", but Frequency fixed and consequent increase of RU costs (and needed contribution)	Market segment: RU can vary any parameter	Line saturated: frequency cannot be increased, just reduced. Prices and capacity can vary.	Service in competition (à la Cournot): frequency cannot decrease, only Price and Capacity can vary	Service in competition. Freq cannot decrease (comp. à la Cournot), nor increase (because line saturation). Only Price and Capacity can vary	Being under PSO, in the short-term Freq is fixed and Fares free. Capacity can vary, too.	Being under PSO, in the short-term Freq can vary just to cover extra-costs. Capacity can vary, too.
1	X	X	X	X	X	X	X	X	X	X	X
2				X		X	X	X	X	X	X
3				X		X	X	X	X	X	X
4				X		X	X	X	X	X	X
5	X	X	X	X		X					X
6	X	X		X	X	X		X			
7	X					X	X	X	X		
8	X	X		X	X	X					
9						X	X	X			
10						X					
11	X	X	X	X	X	X	X	X	X	X	X
12	X	X	X	X	X	X	X	X	X	X	X

Figure 22. Content of the *logit* rules: scenarios with "X" are active, the ones without are inhibited.

[11] Competition "à la Cournot" is a particular behaviour of firms in competition, in which firms set the quantity produced and not the price. It is the typical case of a competition based on frequency rather than on prices, that is called "à la Bertrand". This particular form of competition, that do not generate price-wars but frequency-wars, has been observed in Italian market (*Beria, P., Crozet, Y., & Guihéry, L. (2022). Transport ferroviaire de passagers: la concurrence «sur le marché» s' installe en Europe. Transports, Infrastructures & Mobilité, (533), 37-46*). For this reason, the Cournot scenarios do not allow trainskm to decrease, as none of the competitors would be willing to give up frequencies in favour of the other.

2.3.4   Calculating the derived elasticities

The last step of Figure 8 consists in calculating the derived elasticities of the relevant variable needed for the next steps:

1) $\varepsilon_{REVENUES}$(tac), the elasticity of IM revenues to TAC changes.
2) ε_{PKM} (tac), the elasticity of passengerkm to TAC changes.
3) ε_{TKM}(tac), the elasticity of trainskm to TAC changes.

These elasticities are averages that can be used only in the neighbourhood of the average itself. For example, we impose a variation of the toll of 10% and calculate the average derived elasticities at 10%. In this way we can numerically build elasticity functions, that are, in principle, neither linear nor symmetric around 0%.

An example for one specific line can be found in Figure 23. All elasticities are asymptotical around 0%, which means that for very small variations the effect is percentually larger. Typically, but not always, functions change sign at 0%. The depicted function must be read as follows:

- *For reductions of tolls, the RU is not changing (increasing) the trainskm (ε=0)*
- *For tolls increase, the elasticity is negative, i.e. the RU is cutting trainskm to cope with costs increase. There is a local maximum at 10%, corresponding to the smallest proportional cut. For larger increases, elasticity grows negatively reaching nearly -0,5.*
- *Revenues of the IM are parallel: for increases of TAC, the cuts partially offset the increase, with the worst case at +30%, where half of the TAC increase is lost.*
- *The effect for passengers is instead generally positive: to cope with the increase of costs, the RU adopts a strategy of reducing prices (without increasing trainskm and costs), that positively affects patronage for TAC increases higher than 2-3%. This is possible for this line, whose demand elasticity to prices is large. However, this effect presents a maximum and then tends to zero, as for larger TAC increases the possibility to reduce prices and still breakeven is harder for the RU.*
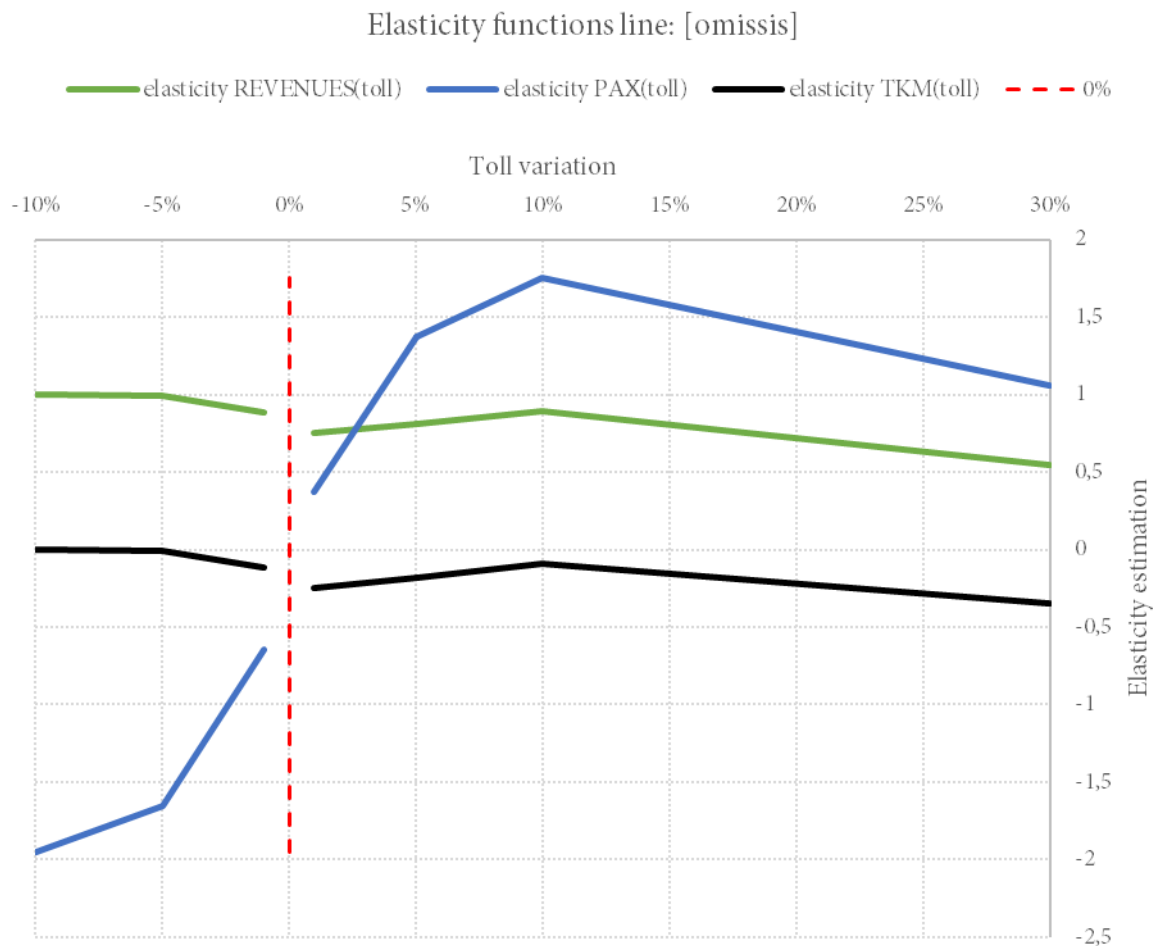
Figure 23. Example of modelled elasticity functions for a line.

Needless to say, this is just an example, and each line presents a different behaviour, depending on its costs structure, the elasticities of demand to prices and frequency, and the market it operates (e.g. in competition or not).
The complete results of the simulations will be presented later, in section 3.

2.4 STEP 3 – PRICING TOOL

Step 3 represents the operational tool to quantify the effects of a pricing scheme, starting from the synthetic elasticities calculated in Step 2. Step 3 is fed with three main inputs (see Figure 24): the elasticity functions coming from Step 2, different pricing schemes to be tested and coefficients used to extrapolate the calculations, done for year 2025, to the remaining years of analysis 2022-2028 (described in a separate Annex).
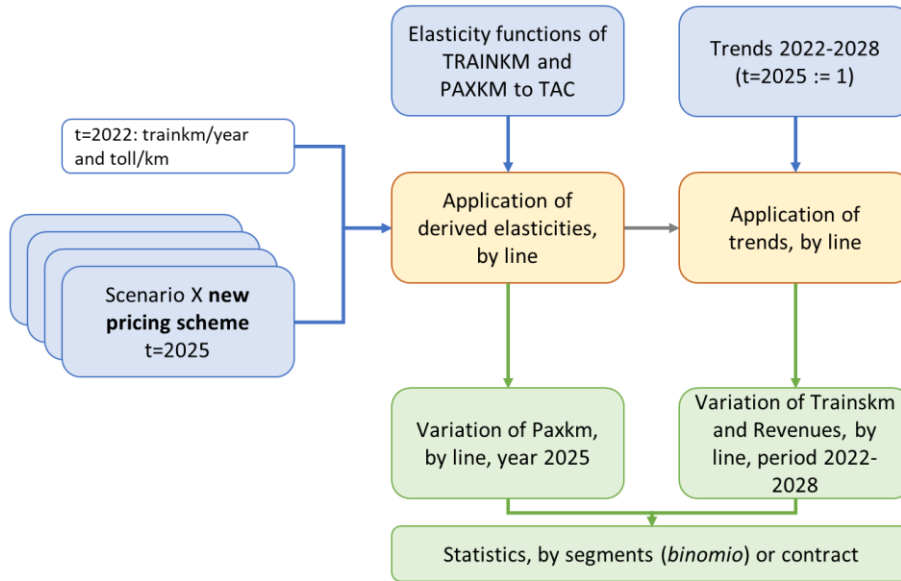
Figure 24. Schematisation of the overall STEP 3 structure. In yellow, the modelling steps.

All calculations are done at the level of the "line" (i.e. groups of homogeneous missions) and finally aggregated for statistical purposes. This means that the final elasticities obtained for a service group (e.g. Regional trains crossing a node) is the average of potentially different situations of responsiveness to TACs.

The pricing scheme, in fact, is the combination of:

- a structure of service groups ("*binomi*");
- a price for each service group;
- the correspondence between one train and a service group.

It is worth underlining that **Step 3 does not entail any pricing criterion, nor performs any optimisation, but simply applies a given pricing scheme** to train supply by means of the computed elasticities. In other words, Step 3 is not deciding how prices are set, but just estimates the effect of those prices, providing quantitative elements for decision. For considerations about the optimality of a pricing scheme, please refer to Section 4.1.

3. PASSENGER TRAFFIC ELASTICITY ESTIMATION

3.1 VALIDATING RU BEHAVIOURAL MODEL

We applied the methodology described in 2.3.3 to estimate the behaviour of RUs and regional governments to the variation of unit tolls. The behaviour is a probabilistic result in terms of share of choice among 12 stylised behaviours. The probabilistic behaviour is used to compute three KPI, namely the trainskm, the passengerskm and the revenues of the IM. From the three KPI, we provide estimations of the three elasticities to the variation of unitary toll (TAC, train access charge). In this way, we can synthesise all the modelling passages in one number, or better, in one *elasticity function* that can be used to simulate the effect of different pricing schemes (section 2.4).

In this section we provide the aggregate results of such estimations and some specific examples. The purpose is of validating of the procedure through the discussion the simulated choices. The model relies on a limited number of parameters, in particular a **calibration parameter** representing the wideness of the probability distribution (k, set to 70 for market services or 100 for regulated services) and the "**constraints**" and "**rules**", described in Section 2.3.3.

The following Table 14 and Table 15 show the results of the behavioural model detailed in the different segments of the previous regulatory period, for two points of the elasticity functions, namely TAC +10% and TAC -10%.

Open access premium market segment
The lines constituting the open access premium market segment are those with the most heterogeneous behaviours. This is due to the different elasticities, but especially to the different types of behaviour represented by the "rules". In fact (Table 13), in group 1 (premium services) only 10-20% of trainskm/year are described as "base", i.e. trains in monopoly and where all logit scenarios can happen. The majority, in particular in groups 1.2 and 1.6, belong to *Cournot competition plus saturation*, which is the typical condition of the Turin-Naples backbone. The other premium services, P-light, are those that limitedly use the HS backbone and in fact are described as *Cournot* (in competition), but not on a saturated network. Conventional trains (3.1) are instead mostly non in competition and on non-saturated lines.

Table 13. Modelled market conditions of Open Access segment, 2022.

	MKT base	MKT saturation	MKT Cournot	MKT Cournot saturation
1.2 Open Access - Nazionali - Premium - Top	10%	0%	9%	81%
1.6 Open Access - Nazionali - Premium - P-base	23%	0%	23%	54%
1.8 Open Access - Nazionali - Premium - P-light	19%	0%	81%	0%
3.1 Open Access - Nazionali - Basic	89%	6%	3%	1%

In case of increase of tolls, for **trains of group 1.2** the prevalent behaviour is that of fares increase (54% of probability), followed by frequency reduction (sc 6 and 7, 24%) and residually fixed supply (sc. 1, 11 and 12 summing up to 15% of probability). In case of price decrease, supply-rigid ones (scenarios 1, 11,

12, together counting more than 70% of cases) prevail. In no cases we observe the rise of the "low-cost model" (sc 9), with a decrease of frequencies and fares.

Segment **1.6 (P-Base)** is, interestingly, quite different: in case of TAC increase almost all scenarios occur, with a large prevalence of fares *decrease* (sc 4 and 9). This is due to the heterogeneity of the group in terms of elasticities and production costs. When TACs decrease, group 1.6 behaves similarly to **1.8 Premium light** and **3.1 Basic conventional market trains**: the prevalent option is a cut of prices that stimulates additional demand thanks to high elasticity. In this sense, the reduction of prices on these segments would be socially optimal. Non-Premium segments are those where fares cuts are frequent also for TAC increases, together with the highest probability of the low-cost model (sc. 9: 13-20%). Being lightly frequency-sensitive, but very price-sensitive, users of these services might increase (but IM revenues fall).

The remaining services, either national PSO (IC and ICN) and regional, are described as much more homogeneous, almost all belonging to the "**REG constrained**" and "**IC constrained**" groups and this makes their results mode homogeneous.

National PSO

The IC segment has been hypothesised as frequency-rigid because of regulatory choices, so the probability is spread among remaining scenarios, in particular a slight decrease of capacity at constant frequency (sc. 12) and a decrease of fares to exploit the high elasticity (sc 4: 20-30%). Frequency cuts are assumed as very limited (5%). The case of TAC reduction is quite similar, with a 20-30% probability of fares decrease and the remaining frequency-constant.

Regional trains

Again, by hypothesis, the regional segment has been modelled homogeneously: all regions are assumed to maintain fixed fares (except for airport services), so the most likely scenario (50-60%) is that of frequency cuts to offset the extracosts. This hypothesis is probably pessimistic for part of the regions, that showed in the past years, a will to invest in the rail system.

The case of TAC decrease gives back mostly rigid scenarios (1, 11, 12) and just 4-10% of frequency increase.

Table 14. Probability of results of RU behavioural model (TAC=+10%)

	1.2 Open Access - Nazionali - Premium - Top	1.6 Open Access - Nazionali - Premium - P-base	1.8 Open Access - Nazionali - Premium - P-light	3.1 Open Access - Nazionali - Basic	4.1 OSP - LP - Notte	4.2 OSP - LP - Giorno	5.1 OSP - REG - Nodo Hub-Sprint	5.2 OSP - REG - Nodo Hub	5.4 OSP - REG - Nodo Ring	5.6 OSP - REG - No Nodo	*Scenario description*
prob sc1	3%	5%	1%	1%	3%	1%	10%	13%	15%	17%	Rigid supply: no change in supply & fares .
prob sc2	6%	4%	1%	1%	2%	1%	0%	0%	0%	0%	Fares are modified (+/-) to compensate (C1=C0) production cost changes (+/-), considering revenues/cost ratio..
prob sc3	54%	6%	0%	1%	0%	0%	0%	1%	0%	0%	Fares increase of +deltaTAC%. Only if TAC increases
prob sc4	4%	41%	47%	60%	20%	35%	0%	0%	0%	1%	Fares decrease of |deltaTAC%|.
prob sc5	1%	2%	0%	3%	5%	3%	64%	57%	53%	46%	Frequency (trainskm) are modified (+/-) to compensate (C1=C0) production cost changes (-/+)
prob sc6	7%	13%	22%	13%	0%	0%	0%	0%	0%	0%	Frequency (trainskm) modified (+/-) of deltaTAC% in response of production cost change (-/+)
prob sc7	17%	16%	5%	3%	0%	0%	0%	0%	0%	0%	Train capacity increase and corresponding frequency (trainskm) reduction to compensate TAC increase (C1=C0). Only if TAC increases
prob sc8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	Train capacity decrease and corresponding frequency (trainskm) increase to compensate costs (C1=C0). Only if TAC decrease
prob sc9	2%	5%	20%	10%	0%	0%	0%	0%	0%	0%	Frequency (trainskm) reduction to compensate extra-costs (C0=C1) and corresponding capacity increase. Fares are reduced in function of extracapacity. Only if TAC increase.
prob sc10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	Train frequency increase and corresponding capacity decrease to compensate costs (C1=C0). Fares are increased of capacity reduction. Only if TAC decreases
prob sc11	3%	5%	1%	1%	1%	0%	5%	8%	10%	12%	Train capacity increase of +deltaTAC%, but fixed frequency (trainskm).
prob sc12	3%	5%	1%	6%	68%	59%	21%	22%	23%	25%	Train capacity decrease of -deltaTAC%, but fixed frequency (trainskm).
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	

Table 15. Probability of results of RU behavioural model (TAC=-10%)

	1.2 Open Access - Nazionali - Premium - Top	1.6 Open Access - Nazionali - Premium - P-base	1.8 Open Access - Nazionali - Premium - P-light	3.1 Open Access - Nazionali - Basic	4.1 OSP - LP - Notte	4.2 OSP - LP - Giorno	5.1 OSP - REG - Nodo Hub-Sprint	5.2 OSP - REG - Nodo Hub	5.4 OSP - REG - Nodo Ring	5.6 OSP - REG - No Nodo	*Scenario description*
prob sc1	26%	13%	7%	4%	3%	1%	26%	26%	26%	25%	Rigid supply: no change in supply & fares .
prob sc2	11%	10%	9%	5%	4%	3%	0%	0%	0%	0%	Fares are modified (+/-) to compensate (C1=C0) production cost changes (+/-), considering revenues/cost ratio..
prob sc3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	Fares increase of +deltaTAC%. Only if TAC increases
prob sc4	7%	48%	71%	71%	21%	37%	0%	0%	0%	1%	Fares decrease of |deltaTAC%|.
prob sc5	0%	1%	0%	1%	2%	0%	4%	6%	7%	9%	Frequency (trainskm) are modified (+/-) to compensate (C1=C0) production cost changes (-/+)
prob sc6	0%	1%	1%	2%	0%	0%	0%	0%	0%	0%	Frequency (trainskm) modified (+/-) of deltaTAC% in response of production cost change (-/+)
prob sc7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	Train capacity increase and corresponding frequency (trainskm) reduction to compensate TAC increase (C1=C0). Only if TAC increases
prob sc8	0%	1%	0%	2%	0%	0%	5%	7%	9%	10%	Train capacity decrease and corresponding frequency (trainskm) increase to compensate costs (C1=C0). Only if TAC decrease
prob sc9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	Frequency (trainskm) reduction to compensate extra-costs (C0=C1) and corresponding capacity increase. Fares are reduced in function of extracapacity. Only if TAC increase.
prob sc10	2%	3%	0%	1%	0%	0%	0%	0%	0%	0%	Train frequency increase and corresponding capacity decrease to compensate costs (C1=C0). Fares are increased of capacity reduction. Only if TAC decreases
prob sc11	26%	13%	7%	4%	2%	1%	14%	16%	17%	17%	Train capacity increase of +deltaTAC%, but fixed frequency (trainskm).
prob sc12	26%	13%	7%	9%	68%	58%	51%	44%	40%	36%	Train capacity decrease of -deltaTAC%, but fixed frequency (trainskm).
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	

To help the **validation of the model**, the following Table 16 shows some examples of model results for about a dozen of types of behaviours (clusters), depending on demand elasticity and cost structure.

Table 16. Clusters modelled of RU/Region/Ministry behaviour to changing TAC.

	Cluster description		Example lines
	+10% TAC	**-10% TAC**	
C1	Mostly fares reduction	Mostly fares reduction	FA Foggia – RM Termini (via BN)
			FR Venezia Santa Lucia – MI Centrale (f. Desenzano)
			EC MI Centrale – Geneve/Bern
C11	Mostly fares reduction, but with a significant (>20%) share of low-cost model (fares and frequency reduction)	Mostly fares reduction	FA Reggio di Calabria Centrale – RM Termini (veloce)
			FR Venezia Santa Lucia – TO Porta Nuova
			FB RM Termini – Ravenna (via Foligno)
C12	Mix of fare reduction and rigid supply	Mix of fare reduction and rigid supply	IC MI Centrale – TO Porta Nuova
			IC Taranto – RM Termini
C2	Mostly fares increase	Mostly rigid supply	italo RM Termini – MI Centrale (MI-RM no stop)
			FR RM Termini – MI Centrale (MI-RM ferma solo a BO)
			MXP MI Centrale – Malpensa aeroporto T1
C21	Mostly fares increase, blended by some frequency reduction	Mix of rigid supply and full-service model (fares and frequency increase)	italo Reggio di Calabria Centrale – MI Centrale
			FR Reggio di Calabria Centrale – Venezia Santa Lucia
C22	Mostly fares increase, blended by some frequency reduction and rigid supply	Mostly rigid supply, blended by some fares reduction	FR NA Centrale – TO Porta Nuova (TO-NA via MI P.Gar, ferma a RE-BO-FI-RM)
			LEO RM Termini – Fiumicino aeroporto
C3	Mostly frequency reduction, blended by fares increase or rigid supply	Mostly rigid supply, blended by some fares reduction	italo RM Termini – Venezia Santa Lucia
			FA NA Centrale – Bolzano
			FA Bolzano – Sibari
C31	Mostly frequency reduction, blended by low-cost model (fares and frequency reduction)	Mix of fare reduction and rigid supply	FA RM Termini – Mantova
			FA Pescara Centrale – MI Centrale (via MI-BO)
			FR Bari Centrale – MI Centrale
C4	Mix of rigid supply and frequency reduction	Mix of fare reduction and rigid supply	italo RM Termini – Bergamo
			IC Reggio di Calabria Centrale – Taranto (via Jonica)
C41	Mix of rigid supply, frequency reduction and fares reduction	Mix of fare reduction and rigid supply	italo NA Centrale – Trieste Centrale
			FR Taranto – MI Centrale (via SA)
			IC PA Centrale – Messina Centrale – RM Termini
C5	n.a.	Frequency increase	FR NA Centrale – Fiumicino aeroporto
			FB PA Centrale – Messina Centrale
C6	Mostly rigid supply	Mostly rigid supply	IC Bari Centrale – RM Termini (via BN)
			RJ Bolzano – Wien
REG	Balanced mix of frequency reduction and rigid supply.	Mostly fixed supply (>80%) and limited frequency increase.	All regional trains

3.2 DERIVED ELASTICITIES ESTIMATES

The final result of elasticity modelling are elasticity functions linking the three KPI of trainskm, paxkm and IM revenues to TAC variations: ε_{TKM}(tac), ε_{PKM}(tac), and $\varepsilon_{REVENUES}$(tac), already described in section 2.3.4. In this section we present the complete estimations for two relevant points, +10% and +10% of TAC (Table 18), including also the result from the application of the simplified "DB model", and later the entire function ranging from -10% to +30% of TAC (Figure 25 onwards). The results are presented in terms of previous market segments ("binomi"), but all elasticities are computed at the line scale. To

complete the information, in Table 17 we report the elasticities of demand as simulated by the transport model, that contribute to the derived elasticity result together with the cost structure.

Table 17. Summary of demand elasticity estimations to price and frequency (source: i-TraM, META/TRASPOL)

	elasticity to price		elasticity to frequency	
	-5%	+5%	-5%	+5%
1.2 Open Access - Nazionali - Premium - Top	-0,594	-0,636	0,069	0,056
1.6 Open Access - Nazionali - Premium - P-base	-1,238	-1,284	0,107	0,063
1.8 Open Access - Nazionali - Premium - P-light	-1,651	-1,788	0,060	0,043
1 Open Access - Nazionali - Premium	**-0,943**	**-0,998**	**0,080**	**0,057**
3 Open Access - Nazionali - Basic	**-1,812**	**-1,862**	**0,139**	**0,116**
4.1 OSP - LP - Notte	-1,500	-1,500	0,000	0,000
4.2 OSP - LP - Giorno	-1,837	-1,810	0,169	0,153
4 OSP - LP	**-1,729**	**-1,710**	**0,114**	**0,104**
5.1 OSP - REG - Nodo Hub-Sprint	-0,349	-0,332	0,175	0,153
5.2 OSP - REG - Nodo Hub	-0,287	-0,267	0,197	0,171
5.4 OSP - REG - Nodo Ring	-0,280	-0,259	0,196	0,172
5.6 OSP - REG - No Nodo	-0,279	-0,257	0,222	0,191
5 OSP - REG	**-0,291**	**-0,271**	**0,204**	**0,177**

Table 18. Summary of derived elasticities to TAC of trainskm, paxkm and IM revenues, for +10% and -10% TAC variations.

	derived elasticities (simulated)						
	method: DB	method: TRASPOL/RFI, +10% toll			method: TRASPOL/RFI, -10% toll		
	ε_TKM	ε_RRFI	ε_PAX	ε_TKM	ε_RRFI	ε_PAX	ε_TKM
1.2 Open Access - Nazionali - Premium - Top	-0,027	0,805	-0,156	-0,177	0,980	-0,125	-0,022
1.6 Open Access - Nazionali - Premium - P-base	-0,059	0,729	0,703	-0,246	0,974	-0,860	-0,029
1.8 Open Access - Nazionali - Premium - P-light	-0,080	0,625	1,055	-0,341	0,995	-1,333	-0,006
1 Open Access - Nazionali - Premium	**-0,044**	**0,757**	**0,284**	**-0,221**	**0,980**	**-0,523**	**-0,022**
3 Open Access - Nazionali - Basic	**-0,080**	**0,761**	**1,321**	**-0,218**	**0,961**	**-1,462**	**-0,044**
4.1 OSP - LP - Notte	-0,048	0,990	0,295	-0,009	0,997	-0,323	-0,003
4.2 OSP - LP - Giorno	-0,060	0,987	0,669	-0,012	0,999	-0,723	-0,002
4 OSP - LP	**-0,056**	**0,988**	**0,549**	**-0,011**	**0,998**	**-0,594**	**-0,002**
5.1 OSP - REG - Nodo Hub-Sprint	-0,022	0,649	-0,055	-0,319	0,953	-0,008	-0,052
5.2 OSP - REG - Nodo Hub	-0,016	0,716	-0,055	-0,258	0,943	-0,012	-0,064
5.4 OSP - REG - Nodo Ring	-0,013	0,760	-0,042	-0,218	0,938	-0,012	-0,069
5.6 OSP - REG - No Nodo	-0,018	0,824	-0,018	-0,160	0,935	-0,039	-0,072
5 OSP - REG	**-0,017**	**0,755**	**-0,039**	**-0,223**	**0,941**	**-0,022**	**-0,066**

Focusing on **trainskm**, the most rigid segment is the **National PSO** one (**4.1 daytime IC** and **4.2 night IC**): the average elasticity to toll increase is 0,011, which means that for an increase of 10% of tolls, trainskm decrease of just 0,1%. The opposite case of TAC decrease is even more rigid. The obvious consequence is that almost the entire TAC variation becomes a variation of IM revenues. This particular result is the outcome of the hypothesis that, being a national PSO, TAC variations are compensated by the

43

contract to avoid cuts, and at the same time there is no room for a frequency increase of existing lines. Two interesting elements must be added:

1. We cannot exclude that a decrease of tolls may open the way to the opening of *new* IC lines;
2. The demand characteristics suggest that the optimal way to "use" a TAC decrease on existing lines is a decrease of fares, with an important result of +14% of new demand for a 10% TAC discount.

The **Premium Market** segment, including full-HS services, has an elasticity of trainskm ranging from -0.177 to -0.341, meaning that a +10% TAC increase determines a limited cut of trainskm of 2-3%. Since the cut is smaller than unitary increase itself, the payoff for the IM is positive, transforming 62 to 80% of the unit increase into revenues, according to sub-segment. Overall, we find a behaviour slightly more elastic than applying the DB model. Interestingly, for the lower segments (P-base and P-light), an increase of TAC gives an important increase of passengers (+7 to +10% respectively), reflecting the possible shift of part of the services to a *low-cost model* (lower frequency and lower prices) or simply fares cut. This result is due to the high elasticity of passengers to fares and low elasticity to frequency (Table 17) found for those segments: the RU benefits both from the cut of trainskm and the rise of passengers.

The opposite case of TAC reduction is almost totally rigid: we expect nearly zero increase of trainskm, rather a further improvement of load factors. Again, this consideration refers to existing services and not to new services, for which a lower TAC may stimulate the opening of new routes or the entry of new operators.

The conventional services (**Basic** segment) are similar to the P-Base and P-Light segments: more elastic to TAC increase than fully-HS and very price elastic. Overall, we expect a cut of 2% of trainskm in front of a +10% TACs, but just +0.4% for a corresponding -10% reduction. Like P-Light, passengers may increase significantly if fares are reduced, also with cuts of frequency.

Overall, the conventional segment (P-Light and Basic) are the ones that is less convenient for IM to price more, with an effect on revenues of 6-7% for a 10% increase.

Finally, the **regional segment** is extremely rigid to TAC decrease (+0.5-0.7% for a -10% TAC) due to the low revenues cost ratio and general difficulties of regional governments to provide extra-budget for the subsidies. The same reasons suggest that TACs increases may generate cuts in supply (-1.5 to -3%) that partially offset the expected revenues increase (+6.5 to +8.5% increase of IM revenues for a +10% TAC increase). The overall effect on passengers is negligible. Interestingly, the most elastic to TAC increase are the upper sub-segments of Regionals (Nodo Hub Sprint), down to the "No Nodo" low performing regional trains out of main city hubs.

Literature is providing limited values for comparison and never with this level of detail. Moreover, literature is generally able to compute only elasticity of trainskm to TAC and seldom the elasticity of final demand, namely passengerkm. For Germany, the application of the above cited method gives for example an elasticity -0.09 of passengerskm to TAC for HS segment. In France, Olarte-Bacares et al. (2022) find an elasticity of trainskm to TAC between 0.404 and 0.448 for HS trains, between 0.13 and 0,17 for conventional trains, no statistically significant result for regional and -0.051 for freight trains. This is not particularly consistent with our figures except for conventional trains, while HS ones are, in Italy, more rigid. This is however not "strange" if we consider that in Italy there is a fierce competition based on frequency, that in Germany is yet to come.

Our average estimates are, as already commented, the cumulative weighted effect of different situations represented by single lines. However, the heterogeneity of elasticities found is different: the highest for upper market segments and the lowest for IC and intermediate for regional trains. See Table 19 for a detail on that.

Table 19. Distribution of elasticities of TKM to UNIT ACCESS CHARGE (increase of 10%). Method TRASPOL/RFI

e_TKM(p+10)	italo	FA	FR	FB	IC	EC	ICN	EN	aerop
less than -1	0%	0%	0%	0%	0%	0%	0%	0%	0%
-1 to -0,975	0%	0%	0%	20%	0%	0%	0%	0%	0%
-0,975 to -0,95	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,95 to -0,925	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,925 to -0,9	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,9 to -0,875	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,875 to -0,85	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,85 to -0,825	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,825 to -0,8	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,8 to -0,775	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,775 to -0,75	0%	0%	3%	0%	0%	0%	0%	0%	0%
-0,75 to -0,725	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,725 to -0,7	0%	0%	3%	0%	0%	0%	0%	0%	0%
-0,7 to -0,675	5%	0%	0%	0%	0%	0%	0%	0%	0%
-0,675 to -0,65	5%	8%	10%	0%	0%	8%	0%	0%	0%
-0,65 to -0,625	10%	0%	0%	0%	0%	0%	0%	0%	0%
-0,625 to -0,6	5%	15%	0%	20%	0%	0%	0%	0%	0%
-0,6 to -0,575	5%	0%	8%	0%	0%	0%	0%	0%	0%
-0,575 to -0,55	5%	8%	0%	0%	0%	0%	0%	0%	0%
-0,55 to -0,525	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,525 to -0,5	0%	8%	0%	0%	0%	0%	0%	0%	0%
-0,5 to -0,475	5%	0%	0%	0%	0%	0%	0%	0%	0%
-0,475 to -0,45	0%	0%	0%	20%	0%	0%	0%	0%	0%
-0,45 to -0,425	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,425 to -0,4	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,4 to -0,375	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,375 to -0,35	0%	0%	3%	0%	0%	0%	0%	0%	0%
-0,35 to -0,325	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,325 to -0,3	0%	0%	3%	0%	0%	0%	0%	0%	0%
-0,3 to -0,275	5%	0%	3%	0%	0%	0%	0%	0%	0%
-0,275 to -0,25	10%	0%	0%	0%	0%	0%	0%	0%	0%
-0,25 to -0,225	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0,225 to -0,2	5%	0%	3%	0%	0%	0%	0%	0%	0%
-0,2 to -0,175	0%	0%	13%	0%	0%	0%	0%	0%	0%
-0,175 to -0,15	5%	8%	10%	20%	4%	0%	0%	0%	0%
-0,15 to -0,125	5%	15%	5%	0%	0%	0%	0%	0%	0%
-0,125 to -0,1	5%	8%	8%	0%	0%	8%	0%	0%	0%
-0,1 to -0,075	5%	0%	5%	0%	0%	8%	0%	0%	50%
-0,075 to -0,05	5%	8%	5%	0%	4%	15%	0%	0%	0%
-0,05 to -0,025	14%	8%	8%	0%	0%	0%	10%	0%	0%
-0,025 to 0	5%	15%	13%	20%	92%	62%	90%	100%	50%
more than 0	0%	0%	0%	0%	0%	0%	0%	0%	0%

In conclusion, Figure 25 to Figure 28 depict the average elasticity functions found, detailed by 1st-tier market segment. Functions are the input of STEP 3 simulations, whose results are reported in section 4.
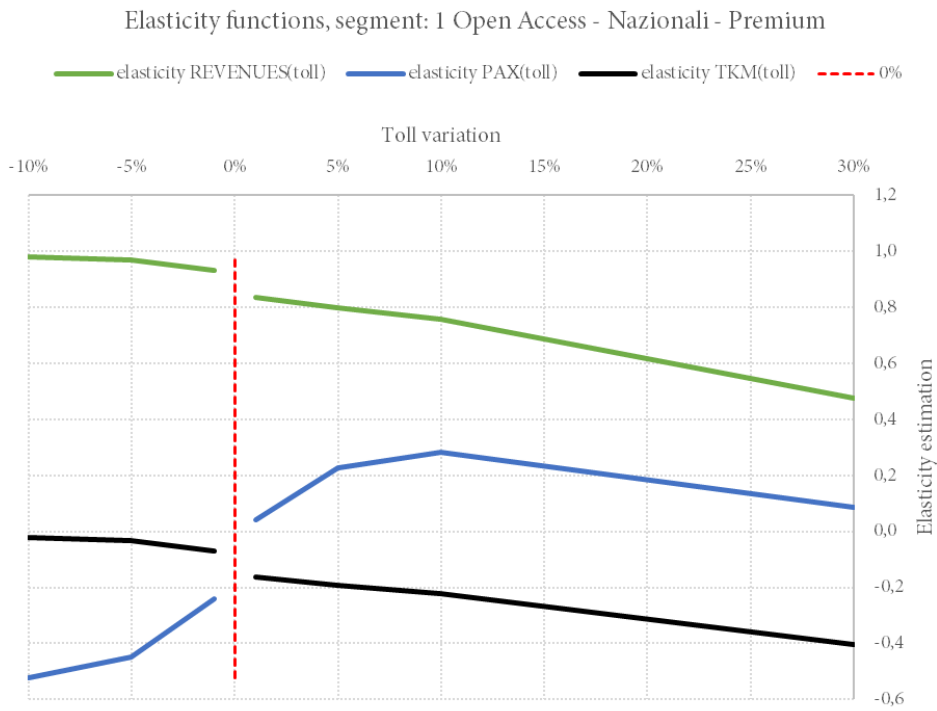
Figure 25. Average elasticity function for segment 1: Open Access Nazionali Premium
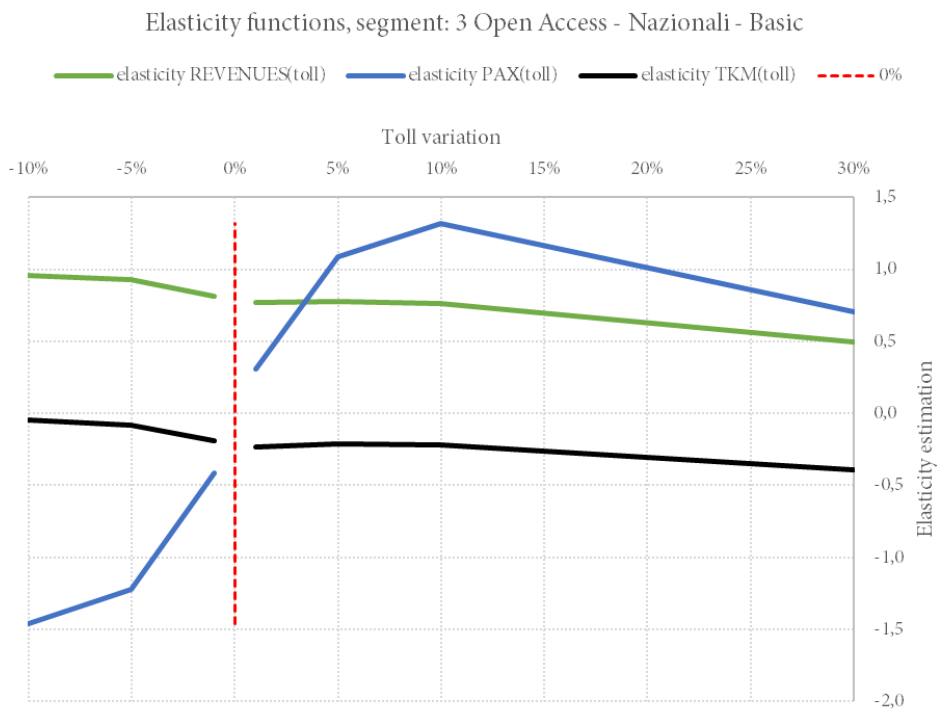

Figure 26. Average elasticity function for segment 3: Open Access Nazionali Basic
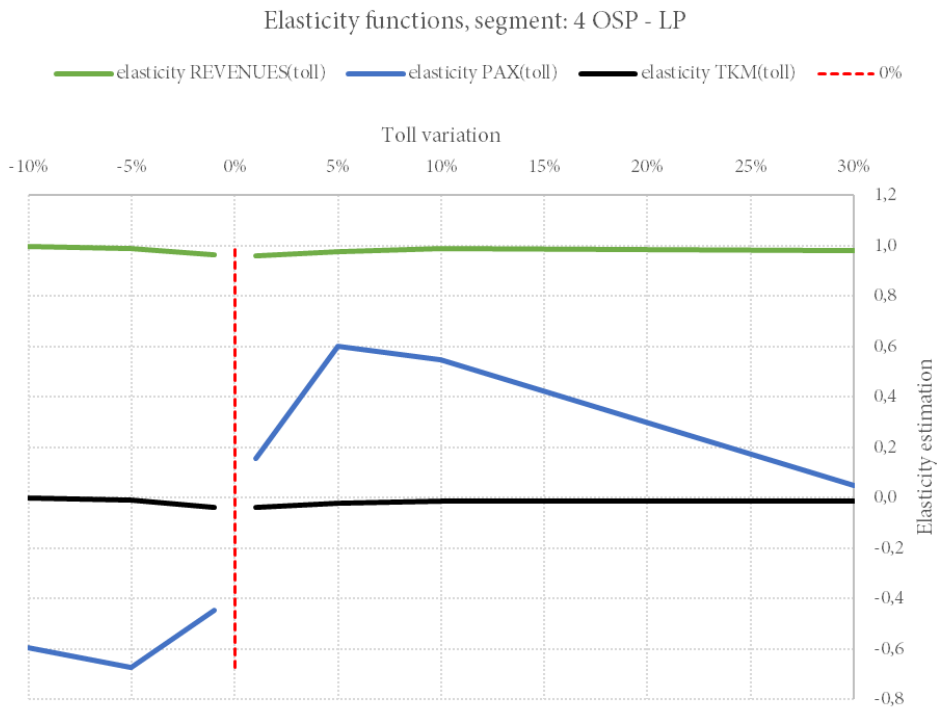
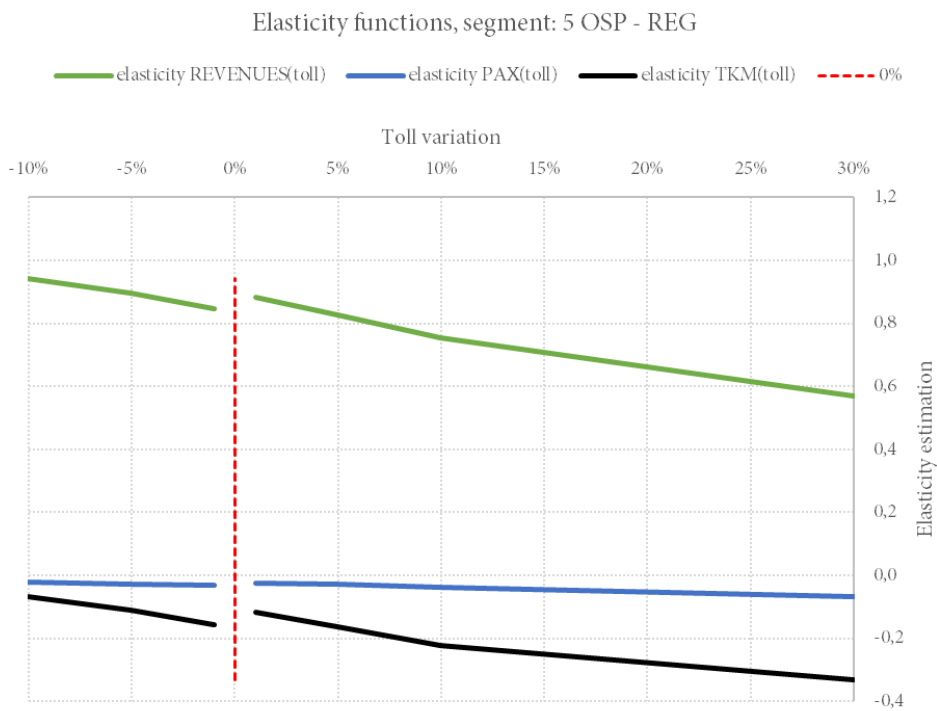**Figure 27. Average elasticity function for segment 4: OSP LP**

Figure 28. Average elasticity function for segment 5: Regional

4. PRINCIPLES OF PRICING ARCHITECTURE

This section concludes the report proposing some theoretical considerations about the possible different principles behind a pricing scheme and some comments about the relationship between the two concepts of *elasticity* and *ability to pay*.

4.1 PRICING CRITERIA

As clarified in Section 2.4, **Step 3 calculations do not assume any pricing criteria**, but just perform the calculations of a *given* set of prices. In this section we comment on which criteria can be practically used to define the prices and their consequences. The issues to be addressed are:
1. Which criteria can be used to set prices of a monopolist with high fixed costs, i.e. a natural monopoly;
2. Which is the optimal perimeter of the monopoly;
3. If and how the most used pricing criteria, the Ramsey-Boiteaux pricing, is applicable as it is to the current case.

A natural monopoly is a product whose cost structure is doomed by a very high share of fixed costs. Neoclassical theory suggests that marginal cost pricing model must be applied to achieve a first-best social optimum: if users were requested to cover also the fixed costs (through average prices), that would cause underconsumption and finally an inefficient use of the asset. This is the classic case of infrastructure such as roads, where consumption-dependent costs are so low with respect to fixed ones, that optimal marginal price is near to zero. For railways the marginal price is not zero, but still low, and leaving (by definition) a *large* part of full costs to be covered by general taxation.

An alternative second-best approach, that is the one promoted by European Commission and typically European States since the directive 2001/14/EC, is that the IMs can levy mark-ups to recover the full cost of infrastructure, but only "when the market can bear it". This principle translates into three different practical approaches (Olarte-Bacares et al., 2022):
a. Ramsey-Boiteux approach;
b. cost causation approach;
c. competitiveness of markets (segments) approach.

Before discussing the pricing approach, one must consider that **a crucial ingredient of a welfare maximisation exercise is the definition of which part of the full costs must be covered by revenues, before than the distribution of such part among the consumers**. The scheme of Figure 29 should help the discussion.

The first case is the one assumed by current situation: full costs are fixed because defined by the efficient cost associated to the current network, and not a larger or smaller one. Also, subsidies are fixed, as there is no discussion on changing the level of yearly contribution. So, the simple application of a Ramsey rule (or another one) to *that particular* residual part cannot be considered a second-best solution. To obtain a second-best solution, one should relax the constraints to subsidies (case 2), but also to the perimeter of service, allowing for more or less production (case 3).
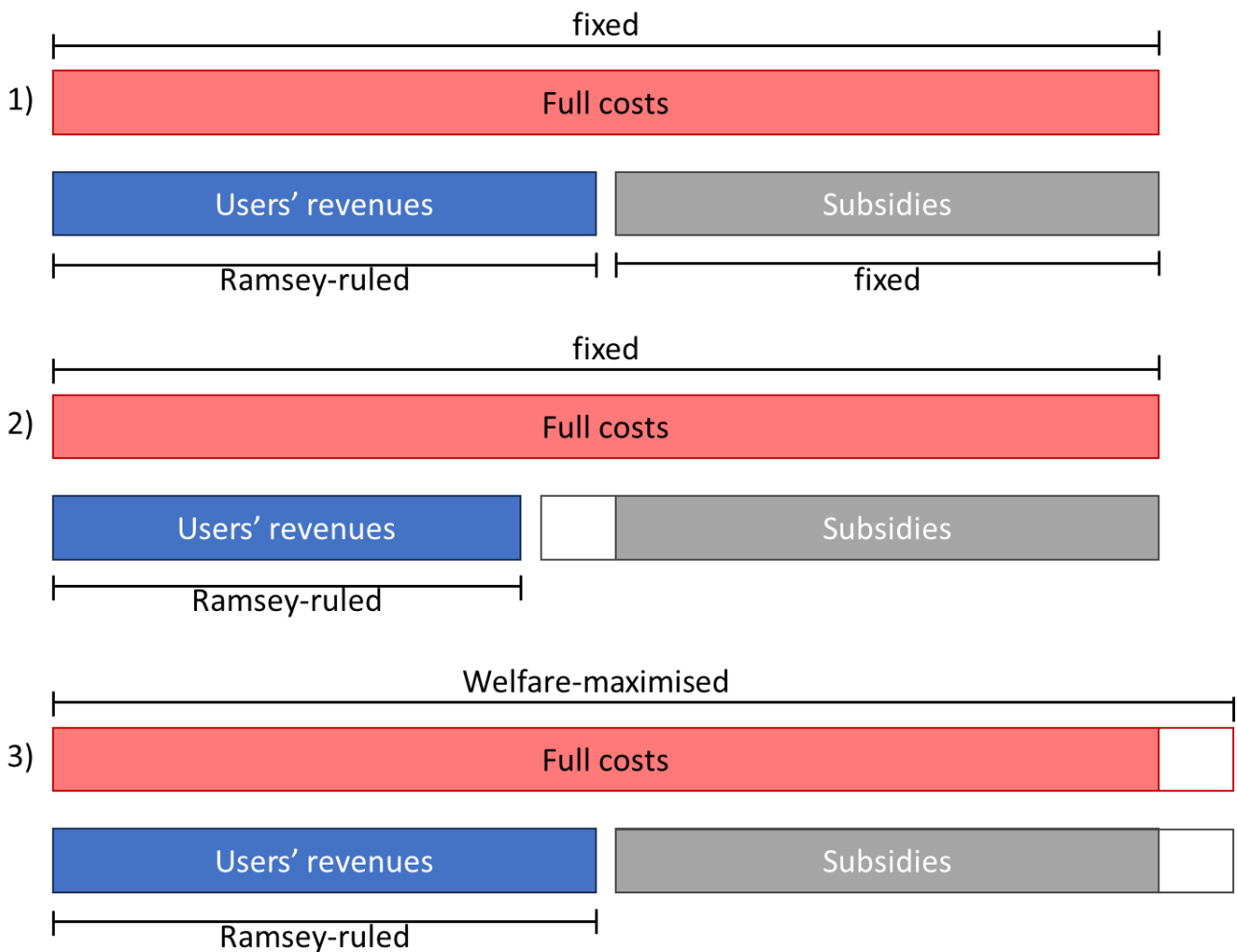
Figure 29. Three cases of full-cost recovery.

4.2 ELASTICITY VS. ABILITY TO PAY

Under EU and Italian regulation based on mark-ups, a key point is then to quantify "if the market can bear" it. Ramsey-Boiteux pricing is seen as the most efficient way to cover both variable and fixed costs (or a part of it, in this case) and at the same time impose the least cost on the overall economy. The principle is to price more the products showing a lower elasticity: in this way, the underconsumption is minimised across products and welfare is (locally) maximised.

$$\frac{p_i - cm_i}{p_i} = -\frac{\lambda}{1+\lambda} \cdot \frac{1}{\varepsilon_i}$$

With: p_i is the optimal TAC for service i, cm its marginal cost, λ the parameter representing the financing constraint and ε the price elasticity of the demand in trainskm to the prices.

It is important to underline that an "inverse elasticity rule" such as the Ramsey pricing is used also by an unregulated monopolist to maximise revenues, but Ramsey pricing of the formula above, including the λ parameter, is giving not only lower prices with respect to monopolistic ones, but also potentially a different ordering (Höffler, 2006).

The commonly applied Ramsey-Boiteaux pricing of the above formula, however, assumes two hypotheses that cannot be ignored during its application:

HP1: the product, in this case the market segment, has no substitutes, which means that demand increases or decreases in response to the price, but does not migrate to other products (i.e. market

segments). For example, we must assume that increasing the tolls of IC trains is not shifting trainskm to RegioExpress. If this were not true, the above formula should be corrected with an additional part that takes into consideration also the cross-elasticities among segments. Unfortunately, these cross-elasticities are even more difficult to be estimated than the direct ones and are not included in the modelling of Step 2.

- HP2: elasticity is constant. Given the general difficulty to estimate elasticities, this hypothesis is commonly adopted. However, it is rarely true, making the application of Ramsey correct limitedly to "that" price level and its neighbourhood, but hardly correct for larger TAC changes.[12] In our case, however, we have provided *elasticity functions* for the passenger segments, and these functions are visibly *not constant* (see Figure 25 to Figure 28). If elasticity is not constant, we can say that **the elasticity is not representing the absolute ability to pay of that segment, but its "ability to pay more (or less)" with respect to initial price level**.

There are two more important points of attention.

Firstly, in the original formulation, the *demand* whose optimisation maximises the welfare function is the final demand of a good (e.g. monopoly prices of a commodity). However, in rail transport, the "demand" of the IM is an intermediate good, namely trainskm, while the demand that must be maximised from a welfare point of view is the final one, namely passengerkm and tonneskm. This introduces a mismatch in what is optimised: **using the inverse of elasticity of trainskm to TAC maximises revenues, but not welfare, while using the inverse of elasticity of passengerskm (or tonneskm) to TAC maximises welfare, but does not guarantee cost coverage**.

Secondly, if the principle of the regulation is the Ability to Pay, one should also take in consideration the budget constraints of the producer. Through the RU behavioural model, we have tried to model the different financial conditions of the products, for example when we have assumed that IC trains are not cut (meaning that we expect more ministerial contributions) while REG trains are (meaning that we do not expect that Regions can subsidise more and that the Ministry will not compensate them). One element that is *not* included in the modelling because company-specific, is that of the **profitability**. The very same train service (same demand, same elasticity of demand, same prices and frequency) is affected differently by a rise of TACs, if the RU makes profits or if the RU has nearly zero margin. In the first case, the RU can well decide to reduce its marginality but remain in the market with the same supply, while in the second case the RU must cut the service or exit the market. The financial situation is not embedded in the calculated elasticities, both because of a practical reason but also because **regulation must be company-independent**.

For this reason, in defining a pricing strategy, it is important to consider **the profitability of rail segments, because a low-margin business will be *less able to bear the cost* of a toll rise with respect to a high-margin one**, independently from the punctual elasticity if calculated as above. Overall, Figure 30 depicts two of the main profitability indicators: the EBITDA and the Net Profit of the four largest Italian passenger companies[13] and the sum of the entire freight market.

---

[12] That elasticities are not constant is something that can be easily figured out looking at real-world cases. In a multimodal equilibrium, the competitiveness of a mode or of a segment may remain constant up to certain levels of toll but rapidly fall if tolls pass a threshold that make – say – road transport much more competitive. See for example the Base segment of Figure 26: elasticity is low and constant up to 10% increases, but then progressively worsens when TAC increase because the producer starts cutting trains *that cannot bear the cost*. The same can be said for freight market: while conventional interconnected trains transporting large quantities of low value goods are and likely remain rigid because of practical absence of alternatives, the competitiveness of combined traffic may over-proportionally worsen above a certain level of tolls, making an entire business not profitable and switch to truck.

[13] In the passengers' segment we ignored the European incumbents SNCF, OEBB, DB, SBB because it is impossible to separate the figures for the Italian services from the ones, largely dominant, of the respective countries.
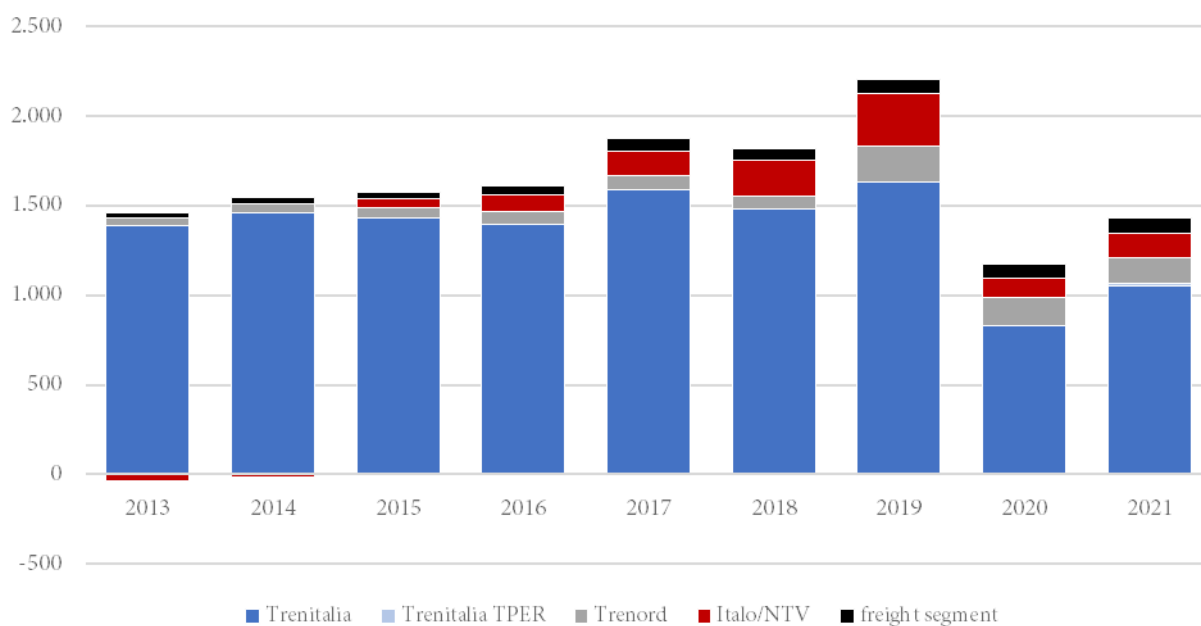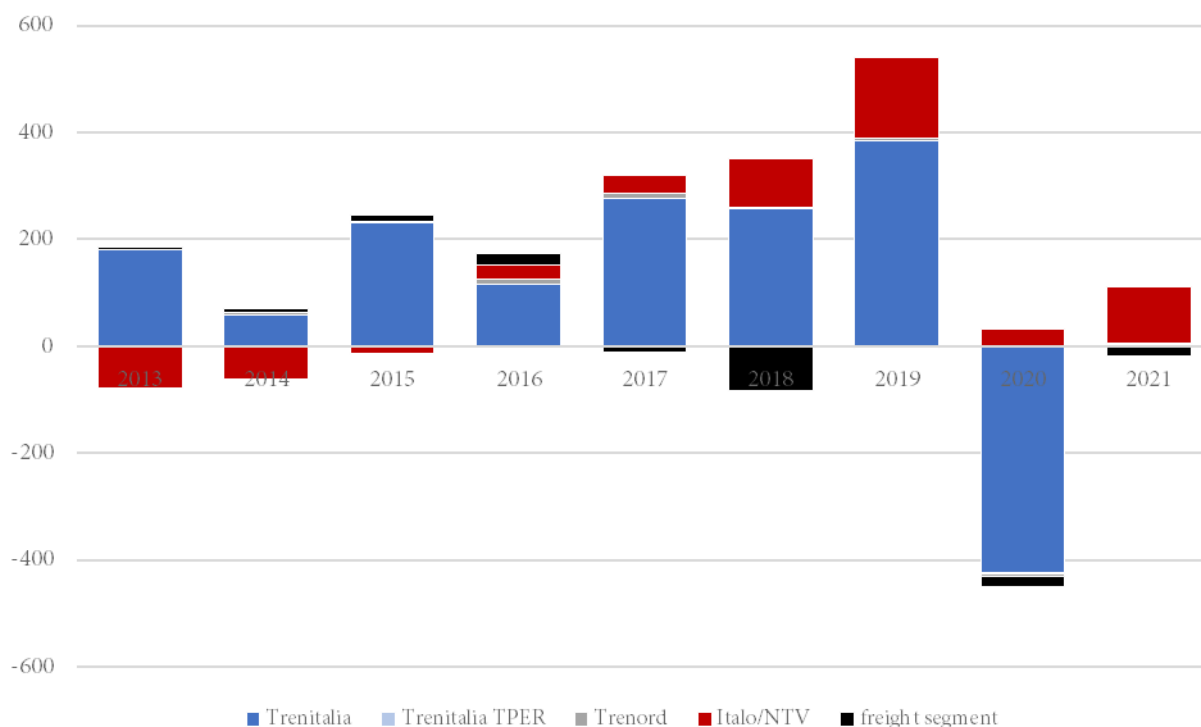
Figure 30. Comparison of EBITDA and Net Profit of the main passengers and freight companies present in the Italian market. Source: our elaborations on Consolidated financial statements from AIDA Bureau van Djik.

Both indicators' message is that freight margins are rather limited, if positive. For example, in 2019 the entire group of freight companies summed up an EBITDA equal to the 3.7% of total EBITDA (82 M€ on 2200 M€). This figure means that **the capability of freight segment to absorb any significant increase of costs looks much more limited than the one of the passenger segment.** The elasticity of single services can instead be used to discriminate **within the segment**. A second argument to be considered

against strictly following a Ramsey rule is that, given the size of the respective markets, a *large* and probably unbearable increase of freight TACs would just *slightly* reduce passengers' TACs.

Summarising, our suggestion is not to apply "as it is" the Ramsey-Boiteaux criterion to set the prices of 1st tier segments ("*binomi*") because:

      a.   we do not have evidence of a constant function of the elasticity for freight demand (ε_{TKM}) (i.e., if it remains always the most rigid segment). Moreover, we know that the elasticity of passengers' segments is *not* constant (see Figure 25 and following) and that they tend to be more elastic with the increase of TACs. In other words, under these conditions, *elasticity* is not a synonym of *ability to bear a cost*;

      b.   welfare maximisation through Ramsey pricing is guaranteed just if the elasticity is the one to final demand (passengerskm and tonneskm), but IM revenues depend from trainskm and thus cost coverage is not guaranteed;

      c.   the margins of the two main submarkets, freight and passenger, are severely unbalanced, with the former just barely profitable;

      d.   the effect of a TAC change on actual total amount of IM revenues is asymmetric between freight and passenger segments, because of the different size of the two.

To cope with the mentioned issues:

- **Practical**: we do not know the elasticity function of freight segment,
- **Theoretical**: Ramsey-pricing is welfare maximising only if elasticities are constant,
- **Political**: subsidies are fixed and not an output of the pricing scheme, so we cannot guarantee that the overall regulation is welfare-maximising, but just – at best – a local optimum.

We suggest proceeding numerically in the following way (schematized in Figure 31):

1. Given the budget constraint and considering elasticity to trainskm, the IM points out **all 1st tier prices sets solutions that guarantee the full-cost recovery (efficient costs)** and no more than that;

2. Among those prices sets, **one is selected considering the inverse of elasticity to paxkm and tonkm provided to guarantee welfare maximisation**. The elasticity of demand to TAC is representing both **the effectiveness of the rail service and proxying the environmental goals**;

3. 2nd tier prices ("*binomi di secondo livello*") are computed again using the inverse elasticity Ramsey formula to trainskm, in consideration of the homogeneity in terms of marginality of services within 1st tier classifications. Given the broad differences of elasticity found among 2nd tier segments, the Ramsey-rule will give back quite different prices, effectively taking into consideration their different *ability to pay more*.[14]

4. The resulting prices set is tested numerically using detailed line elasticities through Step 3, together with other alternative price sets, to provide a numerical proof of the local optimisation.

---

[14] To estimate *if the market can bear a cost* we should also consider margins. However, it is important to underline that we suffer from severe information asymmetries on RUs financial data. Both costs and margins used here are obtained from a simplified model, since we do not have access to any detailed information concerning industrial costs and actual revenues. While for costs we have estimated functions that can be validated, for revenues everything has been managed a-dimensionally and parametrically on passengerskm.
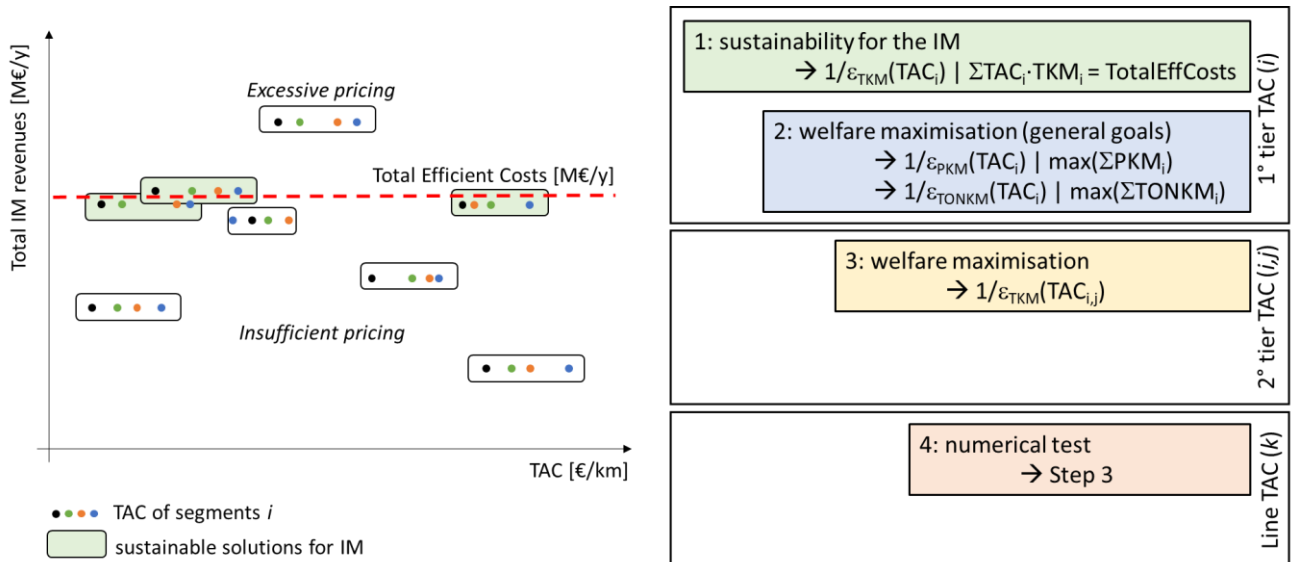
Figure 31. Schematisation of the proposed algorithm for price definition.

5. ANNEX: THE 4-STEPS MODEL I-TRAM

5.1 GENERAL STRUCTURE

i-TraM is a multimodal and multiscale model of the Italian Transport System, jointly developed by TRASPOL and META srl for research and professionals use.

It is composed by five main modules:

- S) **Supply module**, describing the whole set of **infrastructure and network services** (*railway, road, sea shipping and air navigation*) existing at the national level – State of the art of the transport system;
- D) **Demand module**, which estimates all the **passenger and freight movements**, for any purpose, to and from the Italian territory;
- F) **Flow assignment module**, assigning demand and supply to the network, calculating both private and public **traffic flows** for all transport modes;
- A) **Environmental module**, which estimates the impact factors due to traffic, e.g. **energy consumption**, **CO_2 and other air pollutant** (CO, COV, NOx, PM) **emissions**, **noise**, etc.
- E) **Socio-economic module**, which converts the simulation results into **monetary units**, useful to assess financial performances of each system and serves as an input for the eventual cost benefit analysis

The fundamental rationale is to build the model based on **available authentic data** instead of developing sophisticated tools which can't work for the lack of adequate inputs. Special attention is devoted to the continuous interfacing with **National Statistic System** and to the feeding with the existing **Open Data** platforms, thereby resulting in a fast and efficient updating.

Technically, the tool is a regular **four-stage transport model** with an **open architecture** enabling the incorporation of **common software** available in the field of transport planning.

Currently, the traffic assignments are carried out in CUBE 6.1 © environment, using the license released by Bentley to META srl.

5.2 ZONING AND MULTISCALARITY

One of the fundamental features of i-Tram is its multiscale architecture: it can **adapt to the level of detail needed**, simply by thickening/widening the zoning in the study area.

The base configuration of i-Tram includes 1.764 traffic zones (T5 level). With the richness of its databases, the **high number of traffic zones**, and thus the detail, is a strength of the model, which can analyze traffic even at regional/metropolitan level, where the greatest part of mobility demand is concentrated.

Because of its detailed configuration, i-Tram can simulate all the generated trips at national level, of which nearly 80% is interzonal.

Figure 32. Zoning of i-TraM Model.

Traffic zones are defined at different levels: regional (T2), provincial (T3), sub-provincial (T4,T5), municipal (T6), sub-municipal (T7,T8).

5.3 DEMAND MODULE

i-Tram estimates **passenger mobility demand** though a well-established **three stage process**:

- o **Generation:** it estimates the number of trips carried out for every purpose by people living in each traffic zone, segregated in socio-economic categories;
- o **Distribution**: it calculates O/D matrices by purpose, on the basis of many trip attraction functions;
- o **Modal split:** it allocates total O/D matrices on the general transport modes (*walking & cycling, private motorized, public transport*).

The estimate techniques vary according to the **trip purpose**:

- ✓ **Systematic mobility** (home-to-school and home-to-work) is analyzed especially on the basis of the National Census matrices;
- ✓ **Occasional mobility is** the sum of more of 30 entropic sub-models related to different attractors;
- ✓ **Tourist mobility** (trips with overnight stays) is obtained by tourism statistics.

The estimation of **freight demand** is based on a refinement of **ETIS-TRANSTOOLS matrices** (EU DG Transport), carried out on a wide set of functional links among product categories and the location of production/consumption sites.

The basic version of i-TraM is referred to a typical autumn workday, but simulations can cover other time intervals.

5.4 SUPPLY MODULE

5.4.1 Supply database

This module describes the whole set of transport infrastructure at the national level with considerable detail, namely:

- ▪ the entire **railway network** (including regional lines) and other fixed installations (undergrounds, tram lines, funiculars, cableways...);
- ▪ the **road network**, including all motorways and national roads, as well as main provincial and urban roads;
- ▪ the **principal lines of public transport** at urban level;
- ▪ seaports and **sea shipping routes**, as well as inland waterways;
- ▪ airports and **airways**.

A wide set of intermodal connectors details all principal interchanges, allowing for access and transit times.

Moreover, the model includes a full analytic description of **all main transport services at national level**, including: all **air domestic flights** (Table 22), **all railway services** (both national and regional/suburban, see Table 20), **long-haul bus routes** and airport links (Table 21), **ferries** and main **sea shipping routes** to/from the islands, as well as **metro and tram systems** in urban areas.

Table 20. Number of lines per category of service and average daily frequency

	Service group	2019 Lines	Rides	2022 Lines	Rides
A	Frecciarossa (TI)	50	198	78	239
A	Frecciargento (TI)	22	39	26	47
A	.italo (NTV)	28	99	42	119
C	Frecciabianca (TI)	14	32	10	22
C	Intecity (OSP)	50	85	50	89
C	TGV	2	5	2	5
C	Eurocity	16	48	24	57
D	Regionale Veloce, RegioExpress	102	1.081	92	1.017

R	Regionale	720	6.574	728	6.477
R	Servizi sostitutivi	42	385	36	214
S	Suburbani, Metropolitani	174	3.462	170	3.471
M	Metropolitane	32	5.792	32	5.792
T	Tram	104	10.571	104	10.571
X	Auolinee lunga percorrenza e aerop.	871	1.946	736	1.560
Y	Voli domestici	62	409	70	246
V	Voli domestici (low cost)	68	371	182	268
O	Traghetti, navigazione	85	297	85	297
	TOTALE	**2.442**	**31.394**	**2.467**	**30.490**

Table 21. Long-distance coach lines (national and relevant bi-regional ones), year 2019 and 2022. In absence of 2019 timetable, the supply is assumed the same as 2022.

Carrier	*2019* Lines	Rides	*2022* Lines	Rides
ANMO	2	128	2	128
ASAL	6	4,8	4	4
ASHU	2	20	2	20
ATM-Molise			4	10
blablabus	12	8,8	17	20
Bonelli	0	0	0	0
busitalia	19	76	0	0
CAUT	4	1,2	0	0
CEXP	2	2	2	2
ClickBus	0	0	2	12
CTSR	2	14	2	14
di Carlo Bus			2	15
ETSP	0	0	0	0
EZON	0	0	0	0
FAUT	12	8,8	8	8
Ferrovie del Gargano			16	16
FFER	2	10	2	10
Flixbus	209	665	165	353
Gaspari bus			2	12
ISAJ			11	18
ISPA	0	0	0	0
ITABUS	0	0	65	310
LEON	2	10	2	10
LISC	6	10	6	10
LMSA	2	72	2	72
MarinoBus	95	96	95	96
MARZ	13	11,4	13	13
MSPA	4	12	4	12
REXP	2	6	2	6
SATA	4	8,8	2	8
SIAR	2	16	2	16
SIME	8	4,8	8	8
SSAK	1	3	1	3
SSAL	9	34	9	34
STAR	2	28	2	28
Totale complessivo	**422**	**1154,6**	**454**	**1268**

Table 22. Airlines and domestic frequencies, typical day of 2019 and 2022.

Carrier	Wednesday 2019	Carrier	Wednesday 2022
Alitalia	264	ITA Airways	224
Ryanair	157	Ryanair	188
easyJet	52	Wizz Air	32
Volotea	38	easyJet	28
Air Italy S.p.A.	36	Volotea	12
Danish Air Transport	14	AlbaStar	6
Blue Air	7	Blue Air	6
Alidaunia	3	Bahrain Air	4
Ethiopian Airlines	2	Neos	4
Vueling Airlines	2	AeroItalia	3
		Bristow	2
		Gulf Air	2
		Vueling	2
		Edelweiss Air	1
		Middle East Airlines	1

All transport timetables are collected and harmonized in a **national timetable database** (BDO, *Base dati orario*), which generates the **hypergraph** of all public transport services and their combinations.

This supports a **simplified description of the services** in terms of running times and frequencies (>800 national and regional lines), including main urban lines, accompanied by a generic description of other bus lines, suitable for CUBE © platform©.
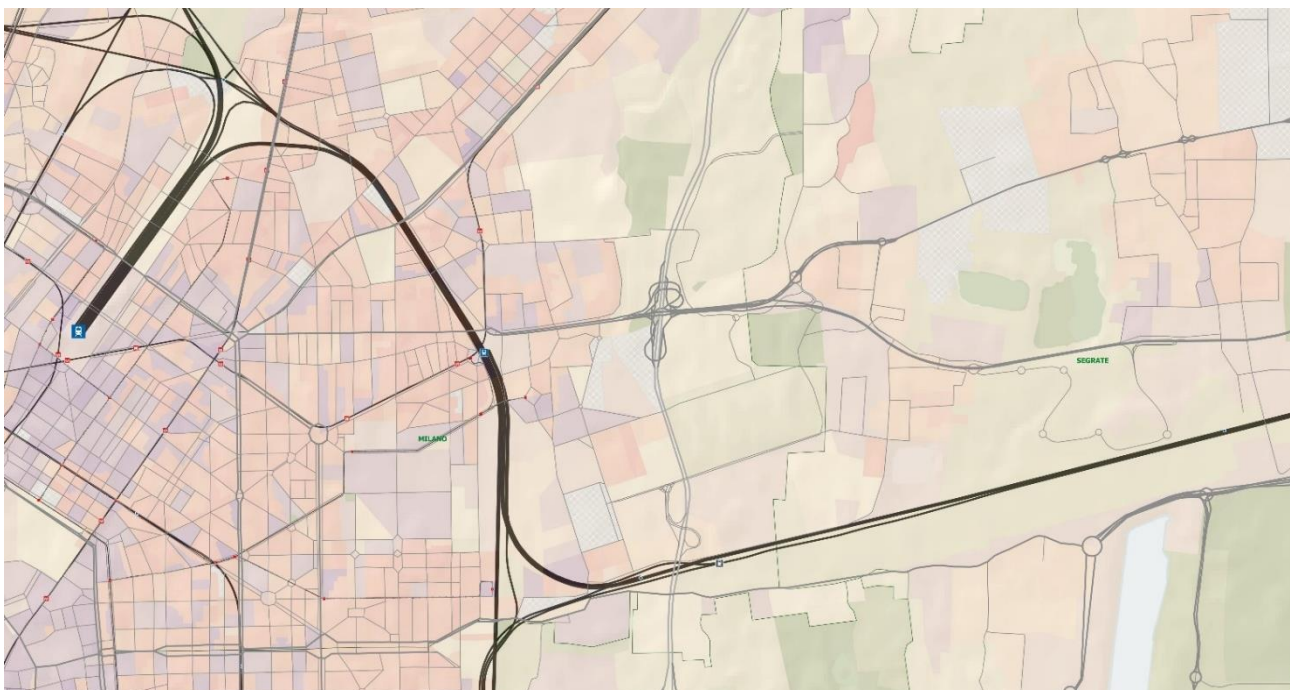

**Figure 33. Transport infrastructure graph.**

Lines and frequencies are defined by grouping single rides according to the following criteria:
- same category of service (e.g. Frecciarossa, Intercity, Regionale Veloce, ecc.),
- a similar sequence of stops ("missione"),
- limited differences of average speed,

- same company.

The grouping in lines is done by means of a semi-automatic procedure determining the "similarity" of paths, considering the model zoning. In fact, it is generally necessary to group single stops in cluseters whose dimension is the same of zoning. This approach allows to group more effectively the rides, considering as similar the stops included in the same zone/cluster and ignoring the stops that are not connected to centroids nor of particular interest for the simulation of interchanges.

The algorithm of grouping works iteratively: initialised with the paths more frequent and regular, is then followed by paths less and less frequent. The path with the higher frequency is defined "master" and "subordinated" paths, if any, are associated to it.
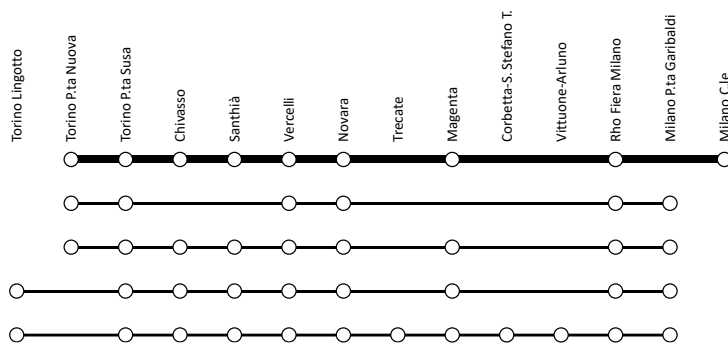
For example, consider the RegioExpress (Regionale Veloce, RV) between Milan and Turin. Analysing the timetable, we can identify a main path with 9 stops, a commercial speed of 81 km/h and 16 rides/day.

In the timetable we can recognise another 4 paths, operated 4 to 1 couples/day and different speeds than the master one (74 to 87 km/h). They differ from the master path for some intermediate stops in secondary stations or because ending in a different station in Milan or Turin. These secondary paths are concentrated in off-peak periods to guarantee higher capacity, are reinforcements of main service during high-demand periods or are aimed at giving an occasional fast service from stations otherwise served by regionals only.

The paths grouped as described originate the "lines" that are the basic unit of the transport model and thus also the minimal unit for results (e.g. elasticity).

5.4.2 Fare functions [CONFIDENTIAL]

[omissis]

5.5 FLOW ASSIGNMENT MODULE

The passenger mobility demand is assigned to the transport network in three different parts
- ✓ **Non-motorized transport**. Pedestrian/bicycles flows are simulated on the basis of shortest paths on specific network (excluding motorways but including pedestrian areas and main bike paths), taking into account fatigue factors.
- ✓ **Private motorized transport**. The assignment of motorized individual mobility is developed on CUBE © platform with an incremental process. Travel times are calculated by BPR functions, whose base speed, capacity and Flow-speed parameters are obtained separately for each road link according to its road type (35 categories), number of lanes, level of local interference (urban/rural segments), etc… The results include a **detailed estimate of mileages and average speed** for single road types, light/heavy traffic, at regional, provincial and local level.
- ✓ **Public motorized transport**. The assignment to the public transport network, considered as a whole, is developed on CUBE © platform. Generalized costs take account of access/egress, waiting, interchange and travel times, line frequencies, fares. The model architecture uses different behavioral parameters for each user class. The results include **mileages and fare**

revenues for each user class and public transport mode and categories (e.g. legacy and low-cost flights, as well as high speed, long haulage conventional, regional and suburban trains).
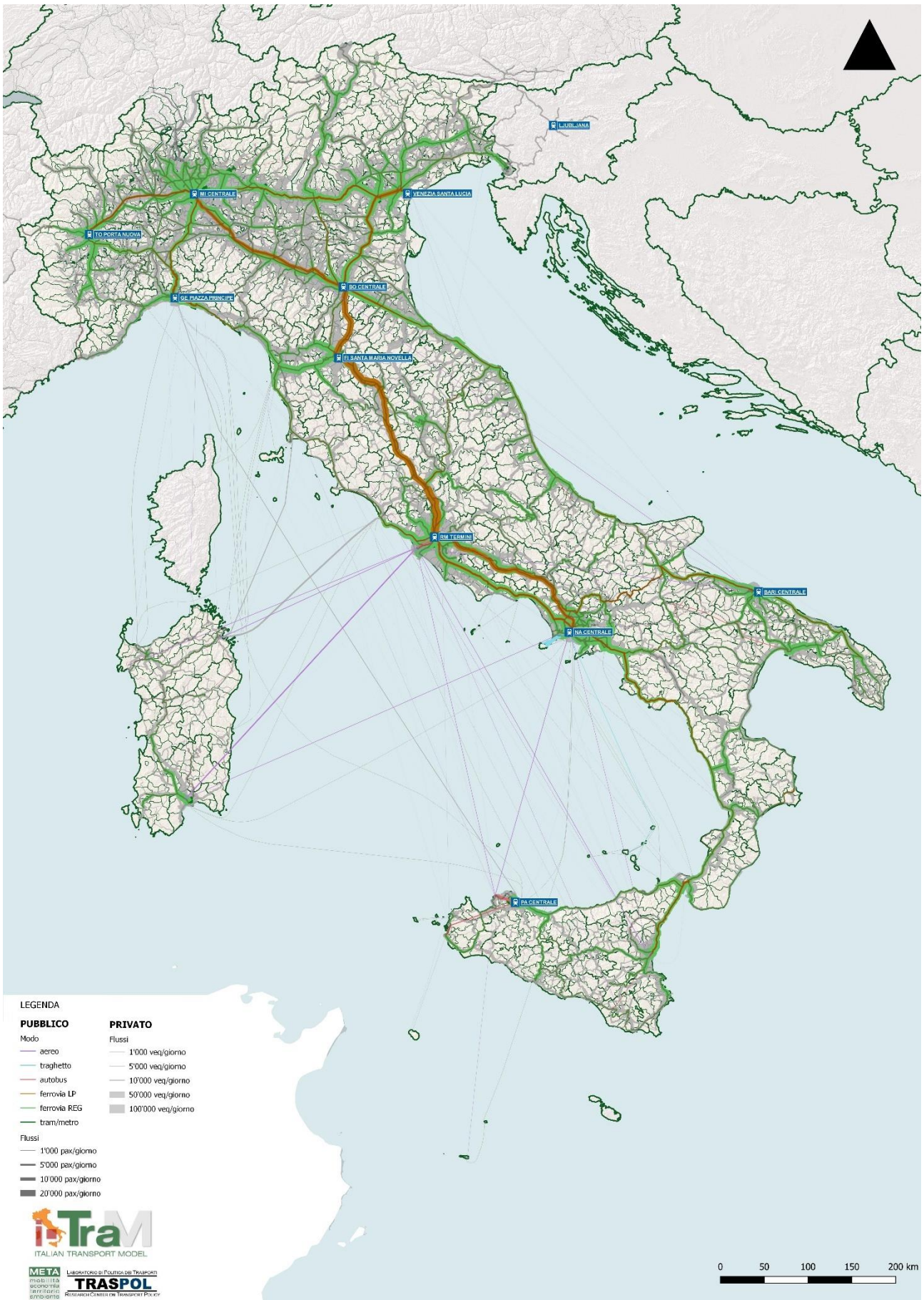

Figure 34. Private transport assignment.

Figure 35. Public transport assignment.

5.6 ENVIRONMENTAL MODULE

The meticulous flow simulations of i-TraM are the basis for the assessment of their impacts on natural and anthropic environment. The model calculates **environmental pressure indicators**, measuring mass/energy exchanges between each part of transport system and the surrounding environment. These indicators can be added by network part, geographic area or transport mode, resulting in aggregate analysis more accurate than those obtained with other tools.

The estimate of environmental indicators is generally obtained using unitary coefficients, describing the impact of each vehicle for a single km run on the network in the simulated speed/flow conditions.

For instance, energy consumption and air pollutant emissions are calculated through the coefficients of the COPERT-CORINAIR european database, suitably fitted to the italian vehicles fleets

Specific calculation modules allows for estimating the expected change of these coefficients due to the possible future evolution of the fleet (e.g. electric car diffusion).

Emissioni di CO$_2$
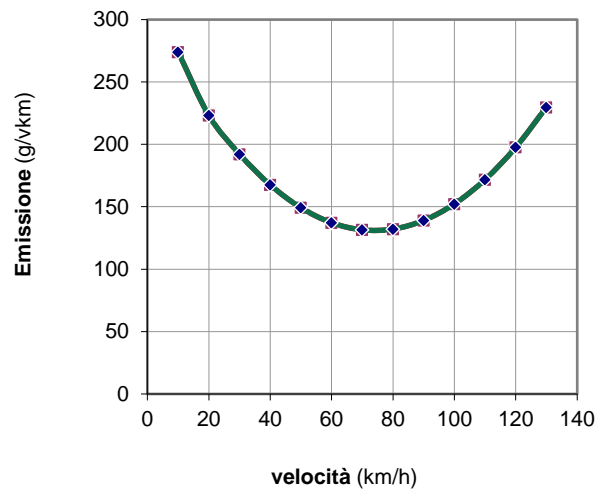
ENVIRONMENTAL PRESSURE INDICATORS

- Land consumption
- Interferences with hydrographic network
- Energy consumption
- Greenhouse emissions
- Air pollutant emissions (CO, COV, NOx, PM)
- Noise
- Water pollution (heavy metal releases on road platforms)
- Interferences with nature reserves and ecological networks
- Urban space occupancy
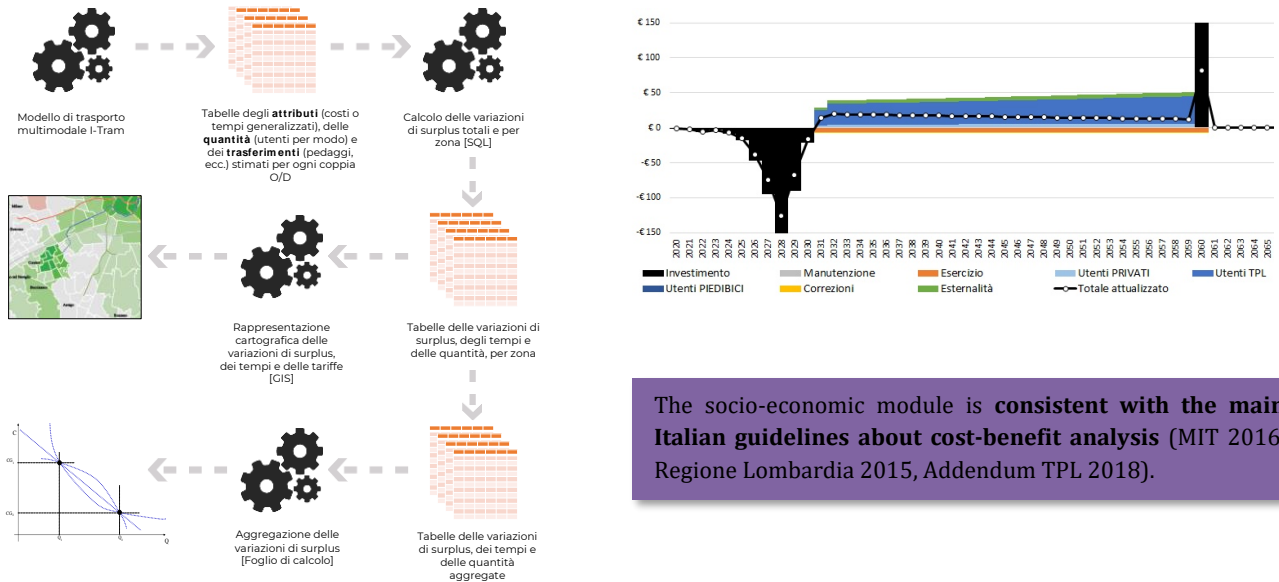- Visual disturbance by traffic

5.7 SOCIO-ECONOMIC MODULE

The socio-economic module of i-TraM can develop financial and socio-economic assessments linked directly, and therefore perfectly consistent, to demand estimation and cost systems at the basis of the whole simulation process.

Thanks to i-Tram, it is possible to associate the simulated scenarios with:

- **production cost estimates** and **financial analysis**;
- **cost-benefit analysis**, including users and environmental impacts.

The socio-economic module is **consistent with the main Italian guidelines about cost-benefit analysis** (MIT 2016, Regione Lombardia 2015, Addendum TPL 2018).

A well-established methodology allows to map user benefit in an effective way, in order to identify the traffic zones which are advantaged, or damaged, by transport projects or policies.
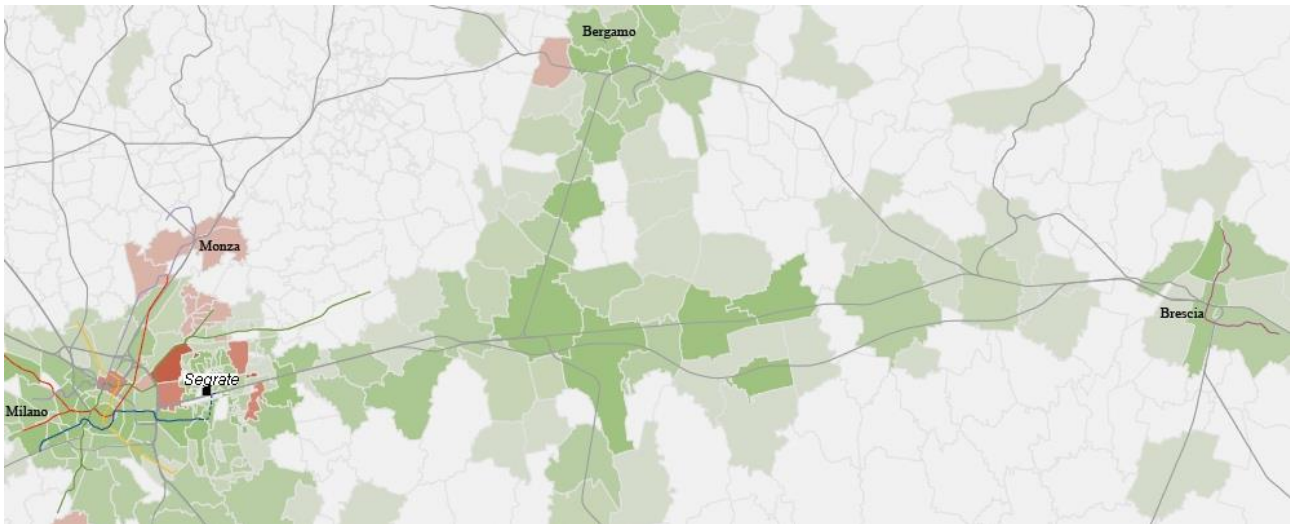

Figure 36. Mapping of costs/benefits.

BIBLIOGRAPHICAL REFERENCES

Beria, P., Tolentino, S., Bertolin, A., & Filippini, G. (2019). Long-distance rail prices in a competitive market. Evidence from head-on competition in Italy. *Journal of Rail Transport Planning & Management*, *12*, 100144.

Beria, P., Tolentino, S., Shtele, E., & Lunkar, V. (2022). A Difference-In-Difference Approach to Estimate the Price Effect of Market Entry in High-Speed Rail. *Competition and Regulation in Network Industries*, *23*(3), 183-213.

Ciuffini F. (2001). Geometria dei sistemi di orario cadenzato. *Sistemi di Trasporto*.

DB Netz (2018). *DB Netz AG Network Statement 2018. Annex 6.1. Description of how the market segmentation, the costs directly attributable to train operation and the full cost mark-ups were derived*.

Höffler, F. (2006). Monopoly prices versus Ramsey-Boiteux prices: are they "Similar", and: does it matter?. *Journal of Industry, Competition and Trade*, *6*, 27-43.

Olarte-Bacares, C. A., Brunel, J., & Sigaud, D. (2022). The impact of access prices on train traffic: An econometric study for France. *Transportation Research Interdisciplinary Perspectives*, *16*, 100679.